BETHLEHEM STEEL CORPORATION
Along the Lehigh River,
North of Fourth Street
Bethlehem
Northampton County
Pennsylvania

HAER No. PA-186

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48-BETH,
18-

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Historic American Engineering Record
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HAER
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18-

HISTORIC AMERICAN ENGINEERING RECORD

BETHLEHEM STEEL CORPORATION
HAER NO. PA-186

Location:	Along the Lehigh River north of Fourth Street and west of the Minsi Trail Bridge, City of Bethlehem, Northampton County, Pennsylvania. UTM: 18.469580,4495980 Pennsylvania Quad: Bethlehem
Date of Construction:	1887-1942
Engineer/Builder:	John Fritz
Present Owner:	Bethlehem Steel Corporation, Bethlehem, Pennsylvania
Present Use:	Heat treatment, weldment and thermos car relining facilities of Bethlehem Plant, Bethlehem Steel Corporation
Significance:	The Beth Forge Division of the Bethlehem Steel Corporation is the earliest and only extant super heavy steel forging facility in the United States. Designed by the noted ironmaster and mechanical engineer, John Fritz, Beth Forge has been a vital supplier of critical components to the U.S. Navy since the 1880s. During World War I it became one of the largest defense plants in the world. Beth Forge was also the profit center around which the modern Bethlehem Steel Corporation was created.
Project Information:	The documentation of the Beth Forge Division of the Bethlehem Steel Corporation was prepared by the Historic American Engineering Record (HAER), National Park Service during the summer of 1990 for the Delaware and Lehigh Canal National Heritage Corridor Commission. This project was also done with the cooperation of the Bethlehem Steel Corporation, the Hugh Moore Historical Park and Museums, Inc., and Lehigh University. It was under the supervision of Eric Delony, Chief and Principal Architect HAER. This report was written by Lance E. Metz, the historian of the Hugh Moore Historical Park and Museums, Inc., Easton, Pennsylvania. When citing this report please credit the Historic American Engineering Record and the author.

Introduction

The BethForge Division of the Bethlehem Steel Corporation is the sole remaining super-heavy-forging plant in the United States and its buildings may be considered a major contributor to the early development of the modern American defense industry. Since the 1880s, Bethlehem has been a vital supplier of critical components to the United States Navy and during World War I, it became one of the largest defense plants in the world. A product of the genius of John Fritz, one of the most technologically innovative of America's nineteenth century ironmasters, the forging division was also the profit center around which the modern Bethlehem Steel Corporation was assembled.

The Bethlehem Iron Company began in response to the iron boom that swept Pennsylvania's Lehigh Valley from 1840 to 1870. During this period the Lehigh Valley, the birthplace of America's anthracite iron industry, became the most productive iron-making region in North America.[1]

The early development of the Lehigh Valley's anthracite iron industry was largely due to the activities of the Lehigh Coal and Navigation Company and its leaders, Josiah White and Erskine Hazard. Under White and Hazard's direction, the Lehigh Coal and Navigation Company completed the Lehigh Navigation in 1829 to link the anthracite coal deposits of what is now Carbon County with the Delaware River at Easton. From Easton, cargoes of anthracite were shipped down the Delaware River to Philadelphia. By 1833, the Lehigh Navigation was also linked to New York Harbor by the Morris Canal, which was joined to the Lehigh Navigation by a cable ferry between Easton and Phillipsburg, New Jersey.[2] The Morris Canal crossed the mountains of northern New Jersey, making accessible the high-grade iron ore deposits of that area. In 1834, the Delaware Division Canal was placed in full operation.[3] Constructed by the Commonwealth of Pennsylvania as a part of its state-built canal system, the Delaware Division Canal joined the Lehigh Navigation at Easton and flowed southward to Bristol on the Delaware River tidewater.

The completion of the Lehigh Navigation, the Morris Canal, and the Delaware Division Canal gave to the Lehigh Valley not only an efficient means of bringing in essential raw materials to manufacturing establishments, but also an important means by which products could be shipped to what were at that time America's two largest metropolitan markets, Philadelphia and New York. These factors, coupled with the Lehigh Coal and Navigation Company's desire to derive additional income by tapping the water-power potential of the Lehigh Navigation, resulted in the creation of the Abbott Street industrial area at Easton, Pennsylvania, during the 1830s. By 1840, Abbott Street was the site of more than a dozen mills and factories employing more than a thousand men that produced a great variety of products ranging from cotton thread, whiskey stills, and rifle barrels to wrought-iron wire, lumber products, and flour.[4] Inspired by the success of Abbott Street, additional water-powered industrial areas were developed along the Lehigh Navigation at other towns such as Allentown and Freemansburg. Abbott Street's success also encouraged White and Hazard to continue their efforts to introduce more industries to the Lehigh Valley. The most important of their activities centered on the development of anthracite-fueled blast furnaces.

As early as 1826, White and Hazard had constructed and experimentally operated an anthracite-fueled blast furnace along the Lehigh River near Mauch Chunk (Jim Thorpe), Pennsylvania. White and Hazard believed that the key to overcoming the persistent problem of getting anthracite to ignite readily in a blast furnace could be solved by heating the air blast before it was injected into the furnace. Unfortunately, the device they constructed to raise the temperature of the air blast could not generate sufficient heat to achieve useful results.[5]

The solution to the problem was eventually provided by Welsh ironmaster David Thomas. In February of 1837, Thomas achieved success in the use of anthracite as a blast-furnace fuel by using an iron pipe stove to heat the air blast at a furnace at Yniscedwyn, Wales, which was owned by his employer, George Crane.[6] These positive results soon came to the attention of Solomon W. Roberts, a prominent engineer and the nephew of Josiah White. Roberts had come to Wales to purchase railroad rails, where he learned of the achievement at Yniscedwyn. He visited Yniscedwyn and reported favorably to his uncle on what he had observed.

Intrigued by the possibilities offered by the successful use of anthracite as a blast-furnace fuel, the managers of the Lehigh Coal and Navigation Company sent Erskine Hazard to Wales to negotiate with George Crane. Crane was reluctant to come to America, but David Thomas agreed to journey to the Lehigh Valley and establish an anthracite-fueled iron-making complex.[7] This new enterprise was organized as the Lehigh Crane Iron Company, which was organized on April 23, 1839. Immediately on his arrival in the Lehigh Valley, David Thomas began to direct the construction of a hot-blast anthracite-fueled iron-making furnace near the small community of Biery's Bridge (Catasauqua) along the Lehigh Navigation. This furnace was placed in operation on July 4, 1840; its success marked the commercial beginning of the American anthracite iron industry.[8]

The quick success of the Crane Iron Company inspired other investors to create anthracite-fueled iron furnaces in the Lehigh Valley. Due to a number of factors, the Lehigh Valley soon became the center of the American iron industry. The Lehigh Navigation's connections to the Morris and Delaware Division canals enabled iron companies to ship pig iron easily to both New York and Philadelphia, the two largest markets for this product. The Morris Canal also facilitated the shipment to the Lehigh Valley of high-grade iron ores from New Jersey. These imported ores were readily mixed with the lower grade ores found in abundant deposits in many parts of the Lehigh Valley. The Lehigh Valley was also blessed with limestone, which could serve as a furnace flux to draw off slag and, through the Lehigh Navigation, it had easy access to an almost unlimited supply of the purest grade of anthracite coal. Most importantly, the Lehigh Coal and Navigation Company encouraged development of iron furnaces by offering cheap supplies of coal and the sale and lease of land and water-power rights along its navigation system.[9] By 1856 more than 19% of America's blast furnaces were located in the Lehigh Valley; by 1873 this region was the site of 55 blast furnaces at 21 different locations, making it the national leader in production.[10]

The anthracite iron industry of the Lehigh Valley was almost exclusively devoted to the production of merchant pig iron, which was sold to foundries and manufacturers that converted it into finished products. However, the Bethlehem Iron Company was different because it was designed to include a rail mill. This divergence can be explained by the large role the management of the Lehigh Valley Railroad played in the creation and subsequent development of this business enterprise.

The Lehigh Valley Railroad was originally organized in 1846-1847 as the Delaware, Lehigh, Schuylkill and Susquehanna Railroad.[11] It remained a paper corporation until 1851 when Mauch Chunk entrepreneur, Asa Packer, purchased a majority of its stock. Packer had earlier accumulated a substantial fortune as a boat builder and contractor for the Lehigh Coal and Navigation Company from which he had later leased large tracts of coal lands. By 1850 he had established his own coal-mining corporation, Packer, Carter and Company. He also engaged in several profitable ventures as a real estate developer and merchant in Mauch Chunk.[12] His primary interest in the Delaware, Lehigh, Schuylkill and Susquehanna Railroad was the creation of an improved means of anthracite transportation which could challenge the Lehigh Coal and Navigation Company's virtual monopoly of the commerce of the Lehigh Valley.

Among the most important of Packer's early actions as the controlling stockholder of the Delaware, Lehigh, Schuylkill and Susquehanna Railroad was the appointment of Robert H. Sayre as its chief engineer. Robert H. Sayre (1824-1907) was a conscientious young man who had acquired considerable experience as an assistant to the Lehigh Coal and Navigation Company's skilled chief engineer, Edwin A. Douglas.[13] Under Sayre's direction, a route that paralleled the Lehigh Navigation between Mauch Chunk and Easton was quickly surveyed and by the time the corporation was reorganized as the Lehigh Valley Railroad in 1853, construction was under way. On June 11, 1855, the Lehigh Valley Railroad was placed in operation; it almost immediately became a profitable enterprise and a serious competitor to the Lehigh Coal and Navigation Company.[14]

During the course of the Lehigh Valley Railroad's construction, large quantities of rails were purchased from the

Lackawanna Iron and Coal Company, located at what is now Scranton, Pennsylvania. It was one of the largest American manufacturers of this product, but its rails were of poor quality and, equally as important, the Lackawanna Iron and Coal Company was controlled by Moses Taylor, a New York entrepreneur, who was also the chief financial backer of the Delaware, Lackawanna and Western Railroad. The D. L. & W. Railroad was at that time being rapidly built across the Poconos to haul anthracite from the Lackawanna Valley to connecting railroads in New Jersey.[15] As a result, every purchase of Lackawanna rails by the Lehigh Valley Railroad was in effect serving as a subsidy for a potential competitor. Unfortunately, the management of the Lehigh Valley Railroad had few options, since almost all domestic rail manufacturers produced, at best, a product of mediocre quality, and superior British rails were expensive due to high tariffs. The solution to this problem was provided by Robert H. Sayre.

Sayre was appointed as general superintendent of the Lehigh Valley Railroad soon after its completion in 1855. Since he also retained his previous position as chief engineer, he exercised effective operational control of this transportation system. His authority and independence of action were also increased by Asa Packer's tendency to serve as an absentee owner who devoted the majority of his efforts to dealing with financiers in Philadelphia and New York. Under Sayre's direction, the Lehigh Valley Railroad rapidly increased its traffic volume and by 1858, Sayre had moved its general headquarters to Bethlehem in order to be closer to the railroad's primary repair shops and its junction points with connecting railroads such as the North Pennsylvania Railroad and the Central Railroad of New Jersey, which provided outlets to Philadelphia and New York respectively.[16] Sayre's move to the new community of South Bethlehem placed him near the center of the Lehigh Valley's rapidly developing iron industry.

In 1857, a Bethlehem merchant, Augustus Wolle, became interested in the development of the Gangewere iron ore beds, which were located in the nearby Saucon Valley near the present borough of Hellertown. To exploit these deposits, Wolle organized the Sauconna Iron Company.[17] Among the initial subscribers was Asa Packer, who directed Robert H. Sayre to take an active role in its affairs. Realizing that the nascent enterprise, if properly directed, could provide an answer to the Lehigh Valley Railroad's rail source dilemma, Sayre used the financial resources of the Lehigh Valley Railroad to take effective management control of the Sauconna Iron Company. The company was reorganized in 1858 as the Bethlehem Rolling Mill and Iron Company, a name which better reflected its intended purpose. Influenced by Sayre, the company established its plant at the junction of the Lehigh Valley and North Pennsylvania railroads.[18] This location enabled the company to ship its products to markets in New York, Philadelphia, and the anthracite regions of Pennsylvania. Sayre also selected the skilled ironmaster who was needed to design the plant and supervise the company's operations. As a result of Sayre's actions, at the inaugural board meeting of the Bethlehem Rolling Mill and Iron Company, the directors hired John Fritz as their General Manager and Superintendent.[19]

John Fritz (1822-1913) was perhaps the most mechanically innovative of America's ironmasters. He had served since 1854 as the superintendent of the works of the Cambria Iron Company at Johnstown, Pennsylvania.[20] In 1857, Fritz had developed an innovative "three high" rail mill which made it possible, for the first time, to produce in America wrought iron railroad rails of uniformly high quality at an economical price. Unlike the commonly used "two high" rail mill, which was composed of only two sets of rolls, the three sets of rolls of the "three high" mill enabled a red-hot wrought iron pile to be completely rolled into a finished rail before it could cool and potentially shatter.[21] The "three high" rail mill was placed in successful operation on July 29, 1857 and John Fritz was granted a patent on his mechanical innovation on October 5, 1858.[22] This patent became the basis for a pool that would eventually involve almost all of the major American rail mills. Under the terms of his contract with the Bethlehem Rolling Mill and Iron Company, Fritz was appointed the general manager and superintendent of the company's works at a salary of $5,000 per annum, although the works were yet to be built. He also received a total of 100 shares of the company's stock to be paid in four annual installments in return for his granting free use of the "three high" rail mill patent.[23]

Despite the ravages of an 1862 Lehigh River flood, work on the manufacturing facilities of the Bethlehem Rolling Mill and Iron Company proceeded rapidly. The entire plant was designed by John Fritz, who also supervised its construction. By the time the No. 1 Blast Furnace was placed in operation on January 4, 1863, the enterprise had been reorganized as the Bethlehem Iron Company.[24] By July 27, the puddling furnace had begun the production of wrought iron blooms for the rail rolling mill and by September 26, the Bethlehem Iron Company had begun the manufacture of high-quality wrought iron rails.[25]

The financial support of the highly profitable Lehigh Valley Railroad enabled the Bethlehem Iron Company to expand its operations during the 1860s.[26] By the end of 1863, the works of the Bethlehem Iron Company had grown to include four stationary steam engines, a blast furnace, fourteen puddling furnaces, nine heating furnaces, a 21" (based on the diameter of the rolls) puddle train, and a 21" rail train. The Bethlehem Iron Company's No. 2 Blast Furnace was constructed in 1867 and a year later a large foundry and machine shop complex was completed.[27] To further increase its pig iron production capacity, the company purchased from the Northampton Iron Company an unused blast furnace located on an adjacent property. The acquisition of No. 3 Blast Furnace raised the company's ironmaking capacity to an annual total of 30,000 tons.[28]

The Bethlehem Iron Company soon won a major share of the eastern railroad rail market due to the superior quality of its product. However, a new product, Bessemer steel rails, began to appear in America during the 1860s, and the superior durability of this British import attracted the attention of major American lines. Although Bessemer steel rails were far costlier than wrought iron rails, they lasted three times longer. As early as 1864 the Lehigh Valley Railroad, under Robert H. Sayre's direction, began to import Bessemer steel rails.[29] This importation was done in response to the activities of the Lehigh Coal and Navigation Company, which was extending its competing Lehigh and Susquehanna Railroad to parallel almost the entire route of the Lehigh Valley Railroad.[30]

The Lehigh Coal and Navigation Company was using imported Bessemer steel rails and Sayre feared that this innovation would greatly reduce the Lehigh and Susquehanna Railroad's maintenance costs and give it an economic advantage over the Lehigh Valley Railroad. In response, he began to prod the Bethlehem Iron Company to investigate the production of Bessemer steel rails.[31] However, John Fritz was opposed to this proposed technical innovation. Fritz had earlier visited an experimental Bessemer steel works at Troy, New York. This plant, which was run by the firm of Winslow and Griswold under the technical direction of Alexander Holley, had installed a small converter and their early results had been poor due to the presence of phosphorus in most American iron ores. Since a phosphorus level greater than 0.02 made steel produced in a Bessemer converter extremely brittle, Fritz felt that the Bessemer process was useless to most American iron makers.[32] Fritz had also witnessed William Kelly's singularly unsuccessful steelmaking experiments in western Pennsylvania during his tenure at Cambria. Kelly's experiments, which were similar in concept to the Bessemer process, had not resulted in a usable product and the failure of Kelly's work had given Fritz additional cause for his reluctance to commit Bethlehem to the construction of a steelmaking plant. Fritz changed his mind upon learning about the key discovery that made it possible to utilize iron that was relatively high in phosphorus in a Bessemer converter.[33]

In its original form, the Bessemer process centered on the introduction of a blast of air into a refractory-lined iron vessel, or converter, that held a quantity of molten pig iron.[34] The oxygen in the air blast ignited and burned away much of the carbon in the pig iron, a process which produced steel. The process was initially developed by British inventor Henry Bessemer (1813-1898), and it was first publicly announced in 1856. However, molten pig iron made from ores that were relatively high in phosphorus produced a brittle metal when subjected to Bessemer's process. This technical problem was solved by the work of pioneer British metallurgist, Robert Forrester Mushet (1811-1891). Mushet found through extensive experimentation that the introduction of a ferromanganese alloy known as Spiegeleisen into a converter produced a metallurgical reaction when blown that reduced the detrimental effects of phosphorus and sulfur and also increased the carbon content of the converter's charge.[35] The resulting steel possessed a hardness and strength that made it suitable for many uses including the rolling of railroad rails. Due to the joint efforts of Alexander Holley, an engineer who had brought knowledge of the Bessemer process to America, Daniel K. Morrell, the general manager of Wood Morrell and Company, the operators of Johnstown's Cambria Iron Company, and Holley's employers, ironmasters John Griswold and John F. Winslow of Troy, New York, an amalgamation of the American rights to the patents of Kelly, Bessemer and Mushet, known as the Pneumatic Steel Association, was created in 1865. In response to the proddings of Robert H. Sayre, the Bethlehem Iron Company became a member of this cartel in 1867.

The entry of Bethlehem into the Pneumatic Steel Association propelled John Fritz to the forefront of the efforts to create a viable Bessemer steel industry in the United States. He quickly absorbed the best available knowledge on the subject through consultations with technical experts.[36] To this knowledge he applied his mechanical engineering genius and together with his brother, George Fritz, the general superintendent at Cambria, and Alexander Holley, he played a large role in the design of the works of the Pennsylvania Steel Company at what is now Steelton, Pennsylvania. This plant was placed into operation in 1867; it was the first commercially successful Bessemer steel plant in America.[37] In 1868, John Fritz went to Europe to examine steel works in England, France, Germany, and Austria.[38] When he returned from this trip, Fritz began work on the Bethlehem Iron Company's Bessemer steel plant. He was aided in this project by Alexander Holley, who made several extended visits to Bethlehem.[39] Due to Fritz's desire to make Bethlehem's plant the most mechanically efficient of America's Bessemer steel works, it was not placed in full operation until October 4, 1873.[40]

In many ways, the Bessemer steel plant that John Fritz designed for the Bethlehem Iron Company can be considered the first serious attempt to achieve integration in the production of both steel and rails. This achievement was early recognized by Fritz's contemporaries. Robert W. Hunt, a pioneering metallurgist, chemist, and mechanical engineer who was involved in some of the earliest attempts to create a Bessemer steel plant in America, described Fritz's plant in the following passage from his work "A History of Bessemer Manufacture in America," which appeared in Vol. 5 (1876-1877) of <u>The Journal of the American Institute of Mining Engineers</u>.

> He arranged his melting-house, engine room,

> converting-room, blooming and rail mills, all in one grand building, under one roof, and without any partition walls. He placed his cupolas on the ground and hoisted the melted iron on a hydraulic lift and then poured it into the converters. The spiegel is also hoisted and poured into the vessels.... Instead of depending upon friction to drive the rollers of the tables, Mr. Fritz put in a pair of small reversing engines.[41]

A more complete description of the blast furnaces, rolling mills, and Bessemer steel plant of the Bethlehem Iron Company is provided in the following passage from the 1873 Guide Book of the Lehigh Valley Railroad:

> The largest manufacturing establishment here is that of the Bethlehem Iron Company, including within its operations, which began in January, 1863, furnaces, rolling mills, machine shop and foundry. Its capital stock is $1,000,000. The measurement of the three stacks is as follows: No. 1, 15 by 63 feet; No. 2, 15 by 45 feet; No. 3, 14 by 50 feet. Their combined capacity is about 30,000 tons per annum. The largest part is used in the adjoining rolling mill, whose capacity is 20,000 tons per annum. Its consumption of raw materials is 70,000 tons of Pennsylvania hematite and New Jersey magnetic ore and from 70,000 to 75,000 tons of coal. The total number of men employed at the works proper is about 700. The new building now erecting for the manufacture of iron and steel will be, it is said, the largest in this country and one of the largest in existence anywhere. It will be 105 feet wide spanned by an iron and slate roof without supportersing columns. It is 30 feet high to the eaves and is in the shape of a double cross of which the long arm [or main building] is 941 feet and the short arms 140½ each, making the area covered 1493 by 105 feet. This is only surpassed by the mill at Creuzot in France, which consists of three buildings 60 by 1400 feet each.
>
> The steel works will start with a capacity of about 600 tons of rails per week, planned and arranged for a threefold increase of the same. There will be three trains of rolls, say 24, 26 and 30 inch diameters, driven by two condensing-engines of 48 and 56 inches diameter cylinders, of 46 and 48 inches stroke.
>
> The mill will be remarkable not only for its enormous size and capacity, but for the many new labor saving conveniences introduced.
>
> The iron work for the building as well as the machinery was all made at the Company's shops and foundry.[42]

Another contemporary description of the Bethlehem Iron Company's productive facilities during the 1870s is contained in the following passage from Frank H. Taylor's 1878 book, Autumn Leaves Upon the Lehigh:

> The extensive works of the Bethlehem Iron Company occupy a large area along the river [Lehigh]. They comprise a Bessemer plant, two large rolling-mills and six blast furnaces, beside supplementary foundry and machine-shops for construction and repairs. A number of valuable iron mines are also owned by the Company. The several railroad lines centering here tend to make this an especially advantageous point for the prosecution of iron manufacture. The reputation for superior quality of steel established by this company is largely owing to the fact that they manufacture their own pig metal and secure for this purpose the best Bessemer ores in the world; drawing their supply largely from Africa, Spain, and our Lake Superior district. The best hematite ores are within easy reach as well as the magnetic ores of the great Cornwall deposit near Lebanon. Ores are also obtained from Lake Champlain being shipped by water to Amboy and thence by rail. A considerable amount also of magnetic ore from New Jersey finds it way to Bethlehem.
>
> The coal used in smelting is anthracite from the Lehigh region and bituminous from the Schroeder mines in Bradford County.
>
> These works were started in 1860 with the erection of an iron rail, a puddle mill and one blast furnace--additional structures having been added at various times as the increasing trade of the concern demanded.
>
> All the buildings are fine, massive, stone structures, the length of the steel mill being 931 feet. The capacity per annum is 60,000 tons steel rails, billets, etc., and 20,000 tons manufactured iron. A full equipment of the most approved appliances for iron and steel may be found here.
>
> At the present time, the Company is engaged in the manufacture of steel rails, rails billets, shovel slabs, etc. and iron rails, cotton ties and band iron.[43]

The most complete and technically accurate description of the works of the Bethlehem Iron Company is contained in a series of articles written by Alexander Holley which appeared in 1877 in the British magazine Engineering. The complete text of these articles is contained in Appendix A of this study.

The steel plant of the Bethlehem Iron Company was the tenth American Bessemer works to begin production.[44] By 1878-1879 it produced over 78,697 tons of steel, a figure that was exceeded only by the 84,356 tons that were produced by the Cambria Iron Company and the 95,475 tons that were produced by the Carnegie group's new Edgar Thomson Steel Company of Braddock, near Pittsburgh.[45] Bethlehem was thus one of the leading steelmakers in a competitive market with no single plant dominating the field. However, the production leadership that the Edgar Thomson works had achieved in 1875-1879 was a harbinger of its latter dominance.

By the early 1880s, the steel works of the Carnegie group and other manufacturers in the Pittsburgh region had assumed a commanding position in the American rail market, gained largely at the expense of eastern railmakers. Kenneth Warren, in his study of America's steel industry, notes several factors that brought about this change. He cites, for example, the sharp lowering of the mining and transportation costs of Lake Superior ores coupled with increased mechanization of unloading facilities at the Great Lakes ports and improved rail transportation from the ports to Pittsburgh. Equally as important, Warren states that many of the eastern railmakers, such as Bethlehem, lacked adequate captive domestic supplies of low-phosphorus iron ores and were forced to depend on foreign mines.[46] Many of the eastern railmakers were further handicapped by the expenses of the tariffs on these imported iron ores and the additional costs of shipping them inland to their plants by railroads. According to Warren, the costs of transporting ore by ship and rail from the Great Lakes to Pittsburgh rose far more slowly than the costs of importing foreign ores and shipping them inland, placing the eastern rail mills at a further disadvantage. Warren also notes that as the eastern railmakers increasingly switched from anthracite to coke for blast furnace fuel, they faced additional costs. Companies such as the Pennsylvania Steel Company, the Lackawanna Iron and Coal Company, and the Bethlehem Iron Company had originally enjoyed favorable locations in relation to the anthracite coal fields. The cost of transporting anthracite to these plants was relatively low, but when coke, because of its higher caloric value, began to replace anthracite as a blast furnace fuel, the eastern railmakers were faced with the much greater costs of the rail transportation of bituminous coking coal from southwestern Pennsylvania. They were further handicapped by the fact that through his control of the Henry Clay Frick Coke Company, Carnegie could supply his steel mills with low-cost coke of superior quality, while the eastern steel companies were forced to pay higher open market prices for their coking coal.[47]

The cumulative effects resulted in an increasing production of rails concentrated at a few large mills. In 1884 there were seventy-one rail mills operating in various parts of the United States. By 1887 many of these mills were closed. During that year an attempt was made to limit competition by forming a rail manufacturing pool composed of the fifteen remaining major producers. However, the pool was not a success and by 1892 Carnegie's plants manufactured almost 25% of the annual total production of rails in America. Carnegie's sucess presented a major dilemma for Bethlehem and the other remaining rail mills due to the fact that as Carnegie increased sales their market share declined. The Bethlehem Iron Company was faced with an ever-shrinking market for its steel rails during the 1880s. As a result, it switched its emphasis to the production of high-grade rails that were rolled from low phosphorus steel billets. It was able to charge a higher price for these rails until competing mills began to make similar products.[49] By 1902, the Bethlehem Iron Company had totally ceased the production of steel rails. However, it continued to prosper and escaped the desolate fate of other eastern rail manufacturers, such as the Troy Steel Company which was closed down and scrapped in 1902, because it developed a new product line centered around the introduction of heavy-forging technology into America.[50]

The impetus for the Bethlehem Iron Company to build a heavy-forging plant came from the decision of the United States Navy to rebuild and modernize its fleet.[51] Although the United States Navy had been among the world's strongest and most innovative maritime forces during the Civil War, the end of hostilities had brought about a rapid American naval disarmament. The National energies were deflected towards settlement of the West and rebuilding of the war-ravaged South. America's ironclads, steam cruisers, and gunboats were mostly sold abroad or tied up to rot in the generally inactive navy yards.[52] Almost no new ordnance was produced, and new technology was neglected. However, by 1881 a series of embarrassing international incidents highlighted the deplorable condition of the United States' fleet. The growing perception that a strong Navy was needed to protect United States' trade and prestige made possible the beginnings of what would become a sustained effort to create a modern battle squadron.[53]

The initial steps toward the creation of an upgraded Navy were initiated by William H. Hunt, who served as secretary of the Navy during the administration of President James Garfield. In 1881, he appointed a group of fifteen naval officers to form a Naval Advisory Board which was charged with the formidable duty of recommending what new types and numbers of warships would have to be built to give the United States Navy an adequate fleet.[54] The Naval Advisory Board was chaired by Admiral John Rodgers and, under his leadership, carefully studied many aspects of both European naval technology and the perceived strategic needs of the United States. Its report, completed in November of 1881, called for a fleet that would be composed of seventy major active and reserve vessels of which eighteen would be unarmored steam powered steel cruisers.[55] Although the high cost of the proposed fleet, which was estimated by the board to be $29,607,000, prevented the report's recommendations from winning congressional approval, the impetus that the board's report began culminated on August 5, 1881, in legislation that provided for the construction of two modern steel cruisers.[56] Although no money was provided to build these warships, another Naval Advisory Committee, chaired by Commodore Robert W. Schufeldt, was created to plan their design. In 1882, the work of this board bore fruit when Congress passed a naval appropriation bill that provided $1,300,000 for three steel cruisers and a dispatch vessel. The cruisers were to be named the U.S.S. Atlanta, U.S.S. Boston, and U.S.S. Chicago, while the dispatch vessel was to be christened the U.S.S. Dolphin. Collectively the vessels would become known as the A.B.C.D. Squadron. The contracts for their construction were won by shipbuilder John Roach of Chester, Pennsylvania.[57]

Construction of the ships of the A.B.C.D. Squadron was fraught with technical problems and cost overruns, which exposed many of the technical and metallurgical deficiencies of the American steel industry. At the same time, the building of these pioneer vessels provided an opportunity for a few perceptive manufacturers to create a new era in the construction of military hardware for the United States.

The new era began with the introduction of open-hearth steelmaking technology into the United States. An open-hearth steel furnace, as described in The Making of Steel (1954), is an enclosed rectangular brick structure containing a depressed elongated saucer-shaped floor or hearth. The hearth is charged with a mixture of scrap steel and molten pig iron; this charge is then swept by tongues of flames from burners at each end until the temperature of the charge is raised to 3000° F. The flames are produced by two large chambers containing a checkerwork arrangement of five bricks through which air or gas can flow freely. These chambers, known as regenerators, are located at opposite ends of the furnace below the level of the hearth. Each of the regenerators is heated alternately by the products of the furnace's combustion. When one regenerator has exhausted its supply of heat to the open hearth, the direction of the furnace's air flow is reversed by valves so that the hot chamber at the opposite end of the open hearth becomes the source of heat flow to melt the charge, while the cool chamber is reheated by absorbing the high temperatures produced by the furnace's combustion process.

Open-hearth furnaces gave steelmakers the ability to control the raw materials that were used to make steel more precisely thus enabling them to produce ingots possessing exactly the physical and chemical properties that were desired. Open-hearth furnaces could be used to make steel of higher quality and greater strength than the far more commonly used Bessemer steels.[58]

Open-hearth technology was introduced into America by Abram S. Hewitt, the principal proprietor of the firm of Cooper and Hewitt which operated a large iron and steel works at Trenton, New Jersey.[59] The spread of open-hearth steel technology was not rapid;

by 1880 less than 10% of American steel was produced by this method. However, the growing use of open-hearth steel in applications such as bridge building, where a high tensile strength was required, brought about its employment in shipbuilding. By 1880, American shipbuilders and steelmakers had developed a body of useful experience in the utilization of open-hearth steel. The availability and superior strength of open-hearth steel led to its adoption as specified material for the structural shapes and plates of the ships of the A.B.C.D. Squadron.[60] Equally as important, open-hearth steel became the preferred material for the production of ordnance armor plate and propulsion machinery parts.

American open-hearth steel ordnance was initially developed by the Midvale Steel Company of Philadelphia, Pennsylvania. Midvale had been founded in 1867 as the William Butcher Steel Company to supply railroad products such as cast steel frogs, switches, car wheels, and locomotive tires.[61] In 1869, this firm installed its first open-hearth furnace and in 1872 it assumed the name Midvale. In 1875, Midvale experimentally manufactured a limited run of three-inch-calibre steel howitzers for the United States Navy.[62] Throughout the late 1870s, Midvale supplied the steel liners that were used in unsuccessful attempts to extend the range and penetrating power of the United States Army's Civil War-era muzzle loading, cast iron, coastal defense Rodman smooth-bore cannon. In 1881, Midvale produced, under the guidance of metallurgist and engineer Russell W. Davenport (1848-1904), an experimental steel six-inch-calibre breech loader for the United States Navy.[63] This gun was the first modern naval gun built in America.

Heavy Forging at Bethlehem

On March 8, 1881, a special joint Army-Navy board was appointed "to make an examination of all inventions of heavy ordnance and improvements of heavy ordnance and projectiles that may be presented to them."[64] On May 18, the board issued its report, which recommended that the use of cast iron for ordnance be abandoned and that forged open-hearth steel become the standard material used for the manufacture of heavy cannon. It justified this recommendation by the fact that the high tensile strength of forged open-hearth steel would better contain the high pressures of the ignition of the large powder charges that were necessary to propel heavy shot and shells through armor plate. In response to the board's report, the United States Senate appointed a select committee of five senators who were charged with the task of investigating what particular types of ordnance would be most suitable to serve as the armament of both naval vessels and sea-coast fortifications.[65] After spirited deliberations, the committee presented its report on February 9, 1883. This document completely condemned the continued use by the Army and Navy of the existing cast iron Civil War-era smooth-bore cannon and acknowledged that heavy forged steel guns were the most suitable type of ordnance.[66] The committee also acknowledged that American steel manufacturers could not adequately mass produce high-strength open hearth steel that was suitable for the manufacture of heavy guns. To alleviate this manufacturing deficiency, the committee recommended that the federal government install the necessary furnace capacity and forging machinery needed to produce the steel for heavy guns.[67] It also concluded that a few steel guns of small calibre should be ordered from American manufacturers to give them much needed experience.

The recommendations of the joint services board also influenced the naval appropriations bill that was introduced in Congress on March 3, 1883. This bill authorized the United States Navy's Bureau of Ordnance to spend up to $100,000 for steel breech-loading guns with the accompanying cartridges and shells.[68] The bill also provided incentives for domestic manufacturers to produce the needed cannon. This provision was written because the United States Navy had been forced to order the forgings for the eight-inch guns needed for the cruisers of the A.B.C.D. Squadron from British steel makers.[69]

Further progress toward the production of heavy ordnance in America was made possible by the appointment of a Gun Foundry Board by Secretary of the Navy William E. Chandler and Secretary of the Army Robert Todd Lincoln in 1883.[70] This six member panel was headed by Commodore Edward Simpson with Captain Edmund O. Matthews and Lieutenant William H. Jaques completing the naval representation while Colonel Thomas G. Baylor, Lieutenant Colonel Henry L. Abbott and Major Samuel S. Elden composed the Army members. After intensive deliberations, the board developed three different proposals concerning the production of heavy ordnance in the United States. The first of these proposals centered on the idea that the federal government would supplement the existing experimental cannon-production efforts of such steel-makers as Midvale by providing additional tools and upgraded equipment so they could begin the production of heavy ordnance. The second proposal called for the establishment of United States Government-owned and -operated plants for the fabrication of weapons while at the same time contracting with steelmaking companies for the necessary forged and tempered open-hearth steel. The third proposal was based on the concept that if the United States Government would place large orders for heavy ordnance with American steelmakers, these concerns would then have sufficient incentive to invest in the expensive equipment necessary to manufacture these items.[71]

In order to evaluate these proposals, the Gun Foundry Board sailed to Europe on July 18, 1883 so they could both investigate the manufacturing methods employed by the leading heavy-ordnance manufacturers and examine the relationships of these concerns to their respective national governments.[72] After visiting such major cannon manufacturers as England's Woolwich Arsenal and the Armstrong Company's works at Elswick, France's Puteaux, Boarges, and Taibes arsenals and being turned away from Germany's famed Krupp Works, the board returned home. On February 8, 1884, it issued its report, which recommended that America adopt a modification of the proven French system of heavy-ordnance production in which semi-finished cannon forgings, were supplied by private steelmakers, were converted into finished artillery pieces.[73] The board's recommendations were accepted by the United States Government; both the Washington (D.C.) Navy Yard and the Watervliet N.Y. Arsenal were eventually selected to be the sites of the navy and army gun factories.[74] To provide the semi-finished steel forgings for these factories, the United States Government solicited bids from American steelmakers. This bid solicitation process provided the opportunity for the Bethlehem Iron Company to enter the military products field by constructing the first and most important heavy-forging plant to be erected on this continent.

The decision of the Bethlehem Iron Company to enter the military products field was a direct result of its search for new sales items to compensate for the progressive erosion of its share of the national market for steel rails. Earlier in this study, it was pointed out that the competitive advantages held by Carnegie's plants and other steelmakers near Pittsburgh resulted in a steady decline in the profitability of many eastern rail mills during the early 1880s. Although the Bethlehem Iron Company remained a profitable corporation, the long-term threat posed by the growing dominance of its Pittsburgh-area rivals became a cause for growing concern. John Fritz had long advocated a diversification of the company's product line, but he had been strongly rebuffed by the directors when he suggested building a plant to roll structural members.[75] His alternative proposal to construct a large capacity plate mill was also rejected. In the face of this rebuff, Fritz turned his attention toward winning the directors' approval of the creation of a heavy-forging plant that would be capable of producing military products.

Fritz's interest in building a heavy-forging plant may have been inspired by an earlier meeting, arranged by Alexander Holley, between John Fritz and John Ericsson, the noted Swedish-born inventor who had created the Monitor and other ironclad warships for the United States Navy during the Civil War.[76] According to H.F.J. Porter, whose retrospective article in the November 23, 1922, issue of Iron Age is the sole historical source for the meeting, Fritz, Holley and Ericsson conferred sometime during the 1877-1879 period at the DeLameter Iron Works of New York, N.Y. Porter maintains it was this conference that planted the seed in Fritz's mind that Bethlehem should begin the production of naval products. Added credence to Porter's statements is supplied by the fact that DeLameter constructed several experimental iron and steel warships during this period, also by the long-time interest of

Alexander Holley in naval affairs,dating to his 1864 trip to Europe to secure the technology needed to finish the Stevens ironclad battery.[77]

John Fritz was also very receptive to a proposal submitted by Lieutenant William Jaques, formerly a member of the Gun Foundry Board. During the board's 1882 fact-finding tour of European armament makers, Jaques formed business ties with the firm of Joseph Whitworth of Manchester, England. Jaques returned to America as Whitworth's agent and soon after the completion of the Gun Foundry Board's report, he was granted in 1885 an extended furlough to pursue this personal interest.[78] Jaques contacted the Bethlehem Iron Company with a proposal to serve as an intermediary between it and the Whitworth Company, should Bethlehem choose to erect a heavy-forging plant capable of producing ordnance for the United States Navy. Since Jaques had served as the secretary of the Gun Foundry Board, he was aware that the United States Navy would soon solicit bids for the production of heavy guns and other products such as armor that would be needed to further expand the fleet. On October 7, 1885, John Fritz, accompanied by Bethlehem Iron Company directors Robert H. Sayre, E.P. Wilbur, William Thurston, and Joseph Wharton, met with Jaques in Philadelphia to entertain a report on his recent visit to the firm of Joseph Whitworth and Sons, Ltd. They discussed the feasibility of Whitworth's supplying the technology that was needed by Bethlehem to enter the heavy forging business.[79] The directors were favorably impressed by Jaques' presentation, which reinforced Fritz's predisposition to diversify Bethlehem's product line, and a decision was made to build a forging plant. The board of directors appointed a special committee, composed of Joseph Wharton, Robert H. Sayre, and E.P. Wilbur, to draw up a contract with Sir Joseph Whitworth and Sons, Ltd. for the purchase of the technology needed to construct a forging plant.[80] By January 18, 1886, the contract with the Whitworth Company had been successfully executed.[81] Soon afterward it was decided to send Fritz and Jaques to Europe to meet with officials of the Whitworth Company and of other leading European forging plants. The enthusiasm that Fritz felt for this project and the vast scale of what he intended can be perceived in the following account of a conversation with Bethlehem's director and general manager, Robert H. Sayre, recorded in <u>The Autobiography of John Fritz</u>.

> As soon as I had their consent to let me go, I got things about the works in the best shape that was possible, so that I could remain from home for a month or so. In this connection, the General Manger one day placed his hand on my shoulder and said "John, you have done more than any other man to draw us in this wild scheme and I am going to hold you responsible for the result." I was not discouraged by this and I told the

> General Manager that I would assume responsibility and that I had much more at stake than he had. I said I knew well that it was a great undertaking and indeed compared with the then existing plants in this country, what I wanted was truly gigantic.[82]

Fritz and Jaques were joined in Europe by director Joseph Wharton. Wharton had learned that Congress would soon approve the construction of armored warships; to prepare for this opportunity he secured the assistance of Henri Schneider and Company of Le Creusot, France, which was the leading manufacturer of steel armor. Wharton's efforts were brought to a successful conclusion with the help of Lieutenant Francis Barber who, like Jaques, had been furloughed from the United States Navy to serve as the American agent of a European steel maker.

While the Bethlehem Iron Company was prepared to import the technology necessary to build America's first heavy forging plant, the United States Navy took another large step in its campaign to create a viable modern fleet. During the spring of 1886, Congress passed a naval appropriations bill that authorized the construction of two armored second class battleships, one protected cruiser, one first class torpedo boat, and the completion of the complete rebuilding and modernization of two Civil War-era monitors.[83] Unlike the ships of the A.B.C.D. Squadron, the two second class battleships (U.S.S. Texas and U.S.S. Maine) would have both large-caliber guns (12" and 10" respectively) and heavy armor plate. As a result, on August 21, 1886, the United States Navy initially solicited bids for 1,310 tons of semi-finished gun forgings and 4,500 tons of steel armor plate. After a period of intensive debate in the Navy Department, a second and definitive solicitation for the ordnance forgings and armor was issued on February 12, 1887.[84] The solicitation allowed interested firms to submit bids on either gun forgings or armor plate, or a combined offer to manufacture both products. It was implied that preference would be given to companies that submitted combined bids. Four American steel companies offered proposals, with the Cambria Iron Company and the Midvale Steel Company bidding solely on ordnance forgings and the Cleveland Rolling Mills of Cleveland, Ohio, bidding solely on armor plate. The Bethlehem Iron Company alone bid on both items. After lowering its bid on gun forgings to meet a lower offer from Cambria, Bethlehem successfully secured both the forgings and armor contracts on June 28, 1887.[85]

In order to fulfill the gun forging and armor plate contracts, the Bethlehem Iron Company completed between 1888 and 1892 the first heavy-forging plant to be built by an American steel company. The plant was designed by John Fritz with the able assistance of Russell Wheeler Davenport, who had entered Bethlehem's employ in 1888.[86] The Bethlehem Iron Company's forging plant was based on technology acquired from the Whitworth Company of Manchester, England, and the Schneider Company of Le Creusot, France. An early description of the forge plant is contained in the following passages from "Description of the Works of the Bethlehem Iron Company" by W.H. Jaques, which appeared in the Proceedings of the United States Naval Institute, Vol XV, No. 4, 1889.

> **Ordnance and Armor-Plate Department.**
>
> This department, now in operation, when completed, will comprise gas producers, open-hearth furnaces, fluid compression apparatus, soaking pits, hydraulic forging presses, plate rolling mill, crucible furnaces, hydraulic and pneumatic cranes, a 125-ton single-acting steam hammer, bending press, oil-treating and annealing shops, and machine shop.
>
> The Open-Hearth Furnaces will have a capacity for casting ingots of 100 tons.
>
> The Hydraulic Forging Presses will produce the largest forgings required for ships of any tonnage thus far designed, and for guns of the largest caliber now in existence. A specialty will be made of hollow forgings of large dimensions.
>
> The Plate Rolling Mill will be capable of supplying all probable demands for rolled plates of every description.
>
> The Pneumatic and Hydraulic Cranes have a capacity of from 25 to 150 tons.
>
> The building containing the open-hearth furnaces, forging presses, fluid compression apparatus, and plate mill is 1155 feet long by 111 feet wide, with transept and annexes for engines, gas producers, etc.
>
> The Oil-Treating and Annealing Shops are conveniently arranged for economical treatment of heavy gun and other forgings, and of armor plates.
>
> The Machine Shop contains lathes, planers, boring mills, slotters, drilling machines, shapers, etc. Among these are: a planer in which 13 feet by 13 feet by 50 feet 10 inches can be planed; 10-foot face-plate lathe; boring mills of the most recent design, and some of the most powerful lathes in existence. The building is 641 feet in length by 116 feet in width.
>
> The traveling cranes are of the pneumatic type, 60 feet span, and from 25 to 100 tons capacity.
>
> The shops are well lighted by electricity, and the entire plant supplied with efficient rail communication and adequate rolling stock.
>
> The casting and forging presses were manufactured by Sir Joseph Whitworth & Co., of Manchester, England, and designed by Mr. Gledhill, Managing Director of that firm; the heavy tools were constructed from designs by Mr. Gledhill and Mr. Fritz; and all erected under the

> latter's direction.
> In the designing and erection of the hammer plant for making armor plates, the plans of Schneider & Co., of Creusot, France, were consulted and followed as far as they met the conditions of construction already adopted.
> This department, for the production of heavy forgings for guns, armor, shafting, and other purposes is rapidly approaching completion, and within a year will equal, if not surpass, any other establishment of its kind in the world in its capacity to supply war material, and the perfectness of its means of rapidly producing the heavy forgings required for modern high-power ordnance and the most powerful armored ships yet designed. With a casting capacity for ingots of 100 tons, fluid compression plant, a steam hammer of 125 tons (falling weight), the most powerful hydraulic forging presses ever constructed, and tools of the most approved and advanced type for shaping and finishing, this company has already manufactured and delivered all of the heavy shafting of the cruisers Philadelphia, San Francisco, and Newark, together with forgings for 4-inch, 6-inch, 8-inch and 10-inch breech-loading rifles, and is now engaged upon the shafting of the armored coast-defense vessel Maine, and 8-inch, 10-inch, and 12-inch breech-loading rifles for both the army and navy, and the armor of the barbette battleship Puritan, the double-turreted monitors Amphitrite, Monadnock, and Terror, the battleship Texas, and the armored cruiser Maine.
> In addition to the war material (including hollow and other forgings for shafting, guns, armor, shields, and conning towers), special and miscellaneous forgings, the works have an output of some 250,000 tons of rails, blooms, and billets, and miscellaneous work, under a personnel of about 3,000.[87]

The complete process for the manufacture of gun forgings of the Bethlehem plant was described in the following paragraphs by Eugene G. Grace in his article "Manufacture of Ordnance of South Bethlehem," Year Book of the American Iron and Steel Institute, 1912:

> All of the steel to be used in the gun whether containing alloys or not is made by the acid open hearth process using especially selected stock and each ingot is fluid compressed to 89 percent of its original volume. The ingot after the examination referred to above is hollow forged under a 5000 ton hydraulic press, and is than rough machined preparatory to tempering. The hollow ingot for 12-inch tube is 16 ft. long, 43¼ in. diameter and weighs 67,700 lbs. When it has been forged and rough

> machined preparatory to tempering, it weighs 28,000 lbs. and in its finished state the tube weighs 18,950 lbs. Correspondingly, the weight of the ingots for all of the forgings for one 12-inch gun is 45,000 lbs. The rough machined weight of the forgings is 196,000 lbs. while the finished gun weighs 148,500 lbs. These figures will give you a fair idea of the large loss in weight the material of the gun undergoes during its fabrication representing a yield from ingot to finished gun of a little over 32 percent.
>
> The specifications for gun forgings are especially drawn to insure in the forgings a close and uniform adherence to the physical qualities assumed in calculating the shrinkages and strength of the gun. The ability to meet these rigid requirements in the successful production of the gun forgings, without excessive and ruinous condemnations, has been acquired only after many years of experience in the gradual development of various processes and products. The forgings are tempered by being heated to varying temperatures depending on their shape and composition and then immersed in oil, or water, as the case demands. They are subsequently annealed and finally submitted to a government inspector who selects official test bars and directs and witnesses the pulling of these bars to ascertain if the forgings meet the prescribed physical qualities and tests are also taken for complete chemical analysis.[88]

The ability of the Bethlehem Iron Company to quickly and successfully enter the heavy forging business can be attributed in large measure to the successful adaptation of European technology by John Fritz and Russell W. Davenport. This process is best described by Davenport in the following except from his 1893 article "Production in the United States of Heavy Engine, Gun and Armor Plate Forgings," which appeared in <u>Transactions of the Society of Naval Architects and Marine Engineers</u>, Vol I, 1893.

> A survey of the field led them to believe that the machinery and methods developed and used by Sir Joseph Whitworth & Company for the manufacture of gun and machine forgings resulted in a product superior in quality to any other known. Through the skillful efforts of Lieut. W. H. Jaques, then of the U.S. Navy, the personal objections of Sir Joseph Whitworth to the duplication of his plant for use in other establishments than his own had been overcome, and in January, 1886, a contract was entered into by the Bethlehem Iron Company with Sir Joseph Whitworth & Co., Limited, for the supply

of a large amount of machinery as well as information. The principal items covered by this contract were as follows:

Two hydraulic forging presses complete, with engines and pumps, one of 2000 and one of 5000 tons capacity, together with two Whitworth hydraulic traveling forging cranes and other necessary appliances for each press; a complete fluid compression plant, including a press of 7000 tons capacity and a 125-ton hydraulic traveling crane for serving it (the upper and lower heads of this press, weighing respectively about 135 and 120 tons, were made at the Bethlehem works); some large machine tools, such as lathes and boring mills, typical of the best development in their respective classes; also designs of open-hearth furnaces and special tools, and an agreement to impart to a practical representative of the Bethlehem Company, to be sent to the Manchester works, full information as to methods and shop practice. There was also a provision that skilled men should be sent by the Whitworth Company to Bethlehem to superintend the erection and starting of the new machinery. Of this provision, however, the Bethlehem Company did not avail itself, but erected and put the plant in operation with its own employees, unaided except by such information as had been gathered by the representatives of the company that had visited the Whitworth establishment. An important feature in the agreement was that all the machinery furnished should represent the latest experience of the Whitworth Company and should be equal in design and execution to similar machinery built new for their own works; it is believed that this agreement was strictly carried out, thus making the Bethlehem plant superior in many respects to the one in Manchester. The money value of this contract was very great, and has rarely, if ever, been exceeded by that of a single order given out by a private concern; this of itself is the best proof of the courage and enterprise of the management of the Bethlehem Company.

While the new machinery was being made at Manchester, buildings of ample proportions were prepared for its reception at Bethlehem; a very fine plant of four open-hearth furnaces of a united capacity of 110 to 120 tons was projected and in part completed, and a machine shop of truly grand dimensions was erected and partly equipped with tools, of which some far exceeded in power and capacity any that had before existed in this country, and of these some of the heaviest were constructed in the Bethlehem shops.

When, therefore, in 1886, Secretary of the Navy Whitney asked American manufacturers to bid on about 1300 tons of steel forgings for heavy cannon and 6700 tons of steel armor plate, bids to be opened March 22, 1887, the Bethlehem Company was already well advanced in its preparation to undertake the manufacture of the former. As is well known, the Bethlehem bids were accepted for both classes of forgings, and contracts for the same were signed in May and June, 1887. Work on the hydraulic forging plant and accessories was pushed with great vigor, and although the delivery of the machinery ordered of Whitworth & Co. was delayed far beyond the dates agreed upon, the first forgings for guns and shafting were produced in the autumn of 1888.[89]

Among the most valued portions of the Whitworth technology was the fluid compression process, which was felt at the time to be the best possible way of preventing the formation of strength-robbing cavities in cooling ingots. A contemporary description of this process was published in the March 14, 1891 issue of Harper's Weekly.

> The furnaces are heated by coal gas. As the molten metal approaches the condition required for casting, specimens are taken out in small ladles and poured into moulds. Immediately on hardening it is broken, and the character of the grain indicates the condition of the fused metal. The furnaces are elevated on an iron platform about fifteen feet above the ground. When all is ready a large vessel fixed on rails, and singularly called a ladle, is placed below the furnace. At a blow of a hammer a valve is opened, and in an instant a torrent of liquid fire, flinging a shower of sparks far around, roars down a channel and fills the ladle with many tons of boiling metal. By hydraulic action the ladle is moved forward until it comes directly over the mould in which the ingot is to be cast. Many pieces of exceptional shape are cast in moulds of sand according to the usual methods. But in the process described here a permanent mould of iron is used lined with fire-brick. The workmen by striking an iron bar through the stream of iron fluid as it drops into the mould start showers of sparks which ignite the escaping gas, and the outside of the mould is thus wreathed with rows of burning jets of flame.
>
> When one ladle is emptied another takes it place until the mould is nearly full. After this is accomplished the ingot is subjected to one of the most tremendous processes to be seen at these extraordinary works. The mould is drawn under a hydraulic press, which is intended to squeeze out all the gas, and reduce the cast to the

> very last degree of condensation and closeness of grain. The press comes down with the remorseless certainty of fate, noiselessly but as terribly as the knife in Poe's famous and horrible story of "The Pit and the Pendulum." When the press strikes the molten iron, flakes of fire are forced up that fly forty or fifty feet, and the by-standers must keep clear of the burning missiles. This press bears down with the stupendous power of several thousand tons. If one were to concentrate the weight of a modern iron-clad ship of war, with guns and equipment and crew, it would scarcely be more than the force concentrated in this the most tremendous engine of mechanical strength yet constructed by man.[90]

Appendix B of this report contains several illustrations of the fluid compression equipment that were published in the June 9, 1900 issue of Scientific American. Modern metallurgical research has shown that the fluid compression process was not as effective as had been originally believed in the prevention of ingot cavities and it has been abandoned. Of the original Whitworth equipment, it is believed that only a single 7000-ton-force bending press remains in active use at the Bethlehem plant. Although the Bethlehem Iron Company had turned to Joseph Whitworth and Company, Ltd. for ordnance-forging technology, they turned to Schneider of Le Creusot, France, for the technology needed to anneal, quench, and temper the completed forgings. This gun annealing, quenching, and tempering facility eventually became the present No. 3 High House of the Bethlehem plant. Its design is first mentioned by Commander F. W. Barber, Schneider's American agent in a letter dated April 18, 1890 from Le Creusot to John Fritz in South Bethlehem: "He [Messr. Bonnard] has complete drawings of the gun tempering plant almost ready to send to Mr. Davenport."[91]

By the autumn of 1890, Bethlehem Iron was successfully delivering gun forgings to the U.S. Navy and was thus able to devote its energies to the completion of the facilities that would be necessary to produce armor plate.

During the early 1880s a vigorous debate was taking place among the world's naval staffs concerning the relative merits of the accepted compound armor, in which a thin hard steel plate was welded to a thicker and more elastic backing of wrought iron, versus the newly developed homogenous steel armor that was produced by Schneider.[92] To resolve this debate comparative test bombardments of compound and homogenous plates were undertaken by the United States Navy and other maritime forces. The results of the United States tests demonstrated that compound armor was prone to both cracking and penetration after repeated hits, while the Schneider homogenous steel armor could be penetrated but not shattered by prolonged bombardment. Homogenous steel armor was also lighter in weight. Recognizing these advantages, the

Bethlehem Iron Company had formed, through the agency of Commander Barber, a contractual alliance by December of 1886 with Schneider's in order to obtain the rights for the production of homogenous steel armor. This production process centered on the forging of specially prepared open-hearth steel plates by a heavy 100-ton steam drop hammer.[93] Bethlehem's foresight was rewarded when the United States Navy decided, after examining the results of comparative armor plate tests, to specify homogenous steel armor for its warships that were under construction.

Since the Schneider process was largely dependent on the power of the steam hammer that was used to forge the plates, John Fritz realized that if the striking power of the steam forging hammer could be upgraded a superior product would result. He designed a monstrous 125-ton steam hammer that was the largest forging device of its type ever to be constructed. Installed at the forge shop of the Bethlehem plant, this gigantic device soon became famous, and a wooden model of it became the centerpiece of Bethlehem's exhibit at the 1892-1893 Columbian Exposition in Chicago. A more detailed description of this great forging machine is contained in the following passage from "The Bethlehem Hammer" which appeared in the July 13, 1893, issue of Iron Age.

> 125 ton hammer-engravings of which we present in our supplement together with a full-sized model which is part of the exhibit of the Bethlehem Iron Company in the Transportation Building of the World's Columbian Exposition.
>
> We have been told by foreign engineers that they were inclined to look on smilingly when the model was being erected, regarding it as a characteristically American piece of bravado. But when almost overnight some of the splendid products of the forge were quietly deposited near the imitation tool, their smiles vanished and a serious and appreciative study of the work followed.
>
> The Foundation - The building of the foundation was itself a very great undertaking. Piles 35 to 40 feet long were driven in the bottom of the pit. Upon them was placed layers of planking covered with wood shavings from a planing machine. The first course of cast iron blocks was laid, there being eight in all. A series of layers of 2 inch planing upon which cork had been nailed followed, the total thickness being 18 inches. Then came a course of ten steel bars forged from ingots with the ends left in the rough . . . . Plank and oak were laid on top of them. Then came a course of four cast iron blocks and then layers of plank and cork and finally six courses of cast iron blocks. Each of these with the exception of the two top courses, which weighed 54 tons, had an estimated weight of 70 tons. It is estimated that

the total weight of metal in the anvil blocks is 2150 tons.

The hammer is rated at 125 tons, that being the combined weight of piston, piston rod and top. It is single acting, the diameter of the steam cylinder being 76 inches, while the stroke is 16 feet 4 inches, which can be increased to nearly 20 feet. The working pressure is 120 pounds. The cylinder is cast in three sections as shown in the weight at the top section being 15,240 pounds while that of the middle section is 20,033 pounds and that of the lower section is 21,005 pounds. The entablature which weighs 60½ tons is so constructed that it is possible at short notice to place a second valve into position should it be required. The legs, it will be observed, are made in two sections, each of the upper sections weighing 48½ tons while the two lower sections 107 tons each. The guides being estimated at 75½ tons. The base plates are 10 x 8 feet each weighing 56 tons.

The piston rod is encircled by an inside split nut upon which is shrunk a forged steel band which is kept from turning by the screw. The piston proper has steel packing rings. A filling to save steam is put into the lower part of the cylinder the arrangement being such that a second inlet valve is provided. The section of the entablature allows the main 21 inch valve, whose ports have been shaped in the manner indicated in order to prevent leakage by scoring. There are 20 inlet ports 15 inches high.

The main valve is commanded by an auxiliary cylinder above which is mounted a small cylinder to balance the valve. The motion of the auxiliary valve is commanded from the pulpit through the two rods which through the system of levers shown activate the slide valve. The lever, which is operated from the pulpit by wire ropes has its shorter arm attached directly to the rod of the operating slide valve. As soon as the piston of the operating cylinder has risen to a certain point, it carries with it the lever system and the latter encircling. It at once acts upon the rod and carries the slide valve back to its original position cutting off the supply of steam. The spring arrangement shown is provided to avoid too rapid opening, and there is a check in the exhaust to stop vibration. The whole arrangement works admirably, the movement of the hammer being under perfect control, the slightest touch of the operating lever making itself felt.

In order to retain the top in any position desired, a series of notches are provided for in the guides by which the top can be locked at any point and from which it can be released from the pulpit through the system of levers.

The exhaust ports in the main cylinder shown keep the piston from rising too high, the upper part of the cylinder acting also as an air cushion.

The upper cast iron part of the top is attached to the lower steel section by shrinking two rings over semi-circular legs cast on the two ports. On the left leg of the hammer is mounted a hydraulic ram for handling the knife to shear off the ends of armor plates. It will be observed that the tracks in the immediate vicinity of the hammer are inclined toward it to facilitate the handling of the forgings. The total height of the hammer above the floor level is 90 feet and its width 38 feet.

The hammer is backed by four large heating furnaces, two on either side, while the manipulation of the masses to be forged is done with two 150 ton overhead traveling cranes running on very heavy lattice-girder tracks resting on posts 17 feet 2½ inches high. The cranes have a span of 40 feet 9½ inches and a total travel of 144 feet. The traversing movement is worked by compressed air while lifting and lowering with a range of 10 feet is done by a vertical cylinder with provision for turning.[94]

The complicated nature of the great hammer and its unprecedented size greatly delayed its completion and it did not become operational until June 30, 1891.[95] After so much effort, its operational life was short. Within three years of its startup it was permanently idled. Several reasons are cited for the demiise of the great hammer. Eugene G. Grace, who later became chairman of the Bethlehem Steel Corporation, stated in his article, "Making Ordnance at Bethlehem," that the shock of the great hammer's blows continually moved out of alignment the large gun-boring and -turning machines that were located in a nearby machine shop.[96] A more cogent reason for its demise is the development of powerful hydraulic presses, which were better able to deform and shape deeper cross sections of large armor-plate ingots. The great hammer was scrapped sometime between 1901 and 1903.[97]

The 125-ton hammer was supplanted during 1892-1893 by an enormous 14,000-ton-force hydraulic forging press. Designed by John Fritz, the press was his last major work for the Bethlehem Iron Company and was constructed to be of great strength and durability. This massive device had two hydraulic forging cylinders that were each 50 inches in diameter. These cylinders gave the press a forging stroke of 8½ inches.[98] The heads of the press were made in two pieces, bolted together by 18 steel bolts, each 6 inches in diameter. Before the heads were bolted, the individual bolts were heated to a red heat. When they had cooled, the bolts were screwed home with a pressure of 20,000 pounds per square inch. The four great column bolts of the press were each 40 feet long and 26 inches in diameter. The entire press was over 47 feet in height and could handle ingots that were up to 14 feet by 14 feet.[99] The dies, forging blocks, and other tools of the press were manipulated by hydraulic power. The press was served by two hydraulic cranes with a capacity of 65 tons each.[100] The hydraulic pressure for the 14,000-ton-force forging press was supplied by a 15,000 horsepower three- cylinder vertical steam pumping engine that was designed by Fritz with the consultation of engineer E.D. Leavitt of the I.P. Morris Company of Philadelphia. Each of the engine's three simple cylinders were 54 inches in diameter and 90 inches high. The engine had a 50-inch stroke and operated at a steam pressure of 150 pounds per square inch. Steam was supplied to the engine by 32 Leavitt boilers, which were housed in a separate building. The engine employed Stephenson valve gear and it operated at the low speed of 80 revolutions per minute. The pumps that delivered hydraulic pressure to the press were attached horizontally to the back of the engine and received their motion from the cylinders through bell cranks with no power being transmitted to the shafts except to and from the flywheels. The arrangement of press, engine, and pumps is illustrated in "Making Heavy Steel Forgings" from the October 1899 issue of Machinery. The pumps supplied a hydraulic pressure of 7,000 pounds directly to each of the cylinders, since there was no accumulator.[101]

The 14,000-ton-force hydraulic forging press was used almost exclusively for the production of armor plate and the largest-sized ordnance and commercial forgings. The majority of the ordnance forgings were shaped by two Whitworth hydraulic forging presses of 5,000-ton-force and 2,000-ton-force capacity. The production of an ordnance forging by these presses is described in the following passage from the June 9, 1900, issue of Scientific American:

> In the manufacture of gun steel with which we are now dealing, the risks of overstrain during the heating are greatly reduced by what is known as hollow forging. Before reheating as above stated, the ingot is put in the lathe and bored throughout its whole length, an operation which not only allows the heat to act from the center outward as well as from the exterior inward, with the result that metal expands evenly throughout its whole mass, and the danger of cracking is entirely removed. After the ingot has been raised to a temperature from 1,800 to 2,000 degrees, a steel mandrel is placed through its center and it is picked up by a powerful overhead crane and taken to the hydraulic forging press. The mandrel serves in some sense as an internal anvil and the work is concentrated upon half of the amount of the metal that it would act upon if the piece were solid throughout. The consequence is that the metal receives more of that "working" which is the very essence of first class forging. . . .

> There are three large hydraulic presses at Bethlehem forge. One of 2,000 tons shown in our illustration, another of 5,000 tons and a third of 14,000 tons. The first two are usually employed upon gun forgings, while the biggest press is kept busy upon the huge masses of armor plate. The hydraulic press is constructed upon the same general lines as the fluid compressor. The hydraulic cylinder is carried in the upper head, and the travel of the piston is controlled by a hydraulic lever in the hands of an attendant. The disk and pointer carried at the side of the press indicate the number of inches of stroke of the piston, and as the same length of stroke is maintained throughout a complete revolution of the forging in the press, the piece if roughed out with an accuracy as to diameter and line that is remarkable and greatly reduces the labor in the machine shop.[102]

Despite the mechanical genius of John Fritz and the metallurgical knowledge of Russell W. Davenport, the Bethlehem Iron Company experienced great difficulties in commencing production of armor plate. Although Fritz and Davenport built on the best contemporary European forging technology to produce a plant of unprecedented size and capacity, the problems of forging armor plate were not easily solved. By 1890, it became clear to the United States Navy that Bethlehem would not be able to meet its contract deadlines for the delivery of armor plate. This delay greatly hindered the completion of such major warships as the first modern American battleships U.S.S. Maine and U.S.S. Texas. The planned expansion of the American fleet therefore necessitated the construction of an additional American armor-plate shop. As a result both of the delay in Bethlehem's delivery of armor plate and of the United States Navy's perceived need for additional American armor-plate manufacturing capacity, Secretary of the Navy Benjamin Franklin Tracy began negotiations with the Carnegie Phipps Company of Pittsburgh, Pennsylvania, for the construction of an armor mill. On November 20, 1890, the United States Navy signed a contract with Carnegie Phipps for 6,000 tons of armor plate.[103] Significantly, the contract specified that the plate could be manufactured from simple steel or nickel steel.

During the late 1880s French steelmakers conducted experiments with nickel alloy steel armor plate, which demonstrated a marked superiority of this product over the standard simple steel and compound wrought iron-steel armors. As early as the autumn of 1889, the United States Navy secured an experimental batch of Schneider nickel steel armor.[104] In order to evaluate the protective strength of nickel steel armor, a series of comparative tests were held at the United States Navy's Annapolis proving grounds during September of 1890. These tests pitted the Schneider nickel steel plates against simple steel plates and a British compound wrought iron-steel plate. Although the compound plates were quickly demolished under the bombardment of 6-inch and 8-inch armor-piercing projectiles, the nickel steel plate appeared to exhibit only marginally better resistance to penetration than did the simple steel plate. However, it was much more resistant to cracking, which was the greatest fear of the Navy's technical experts.[105]

In response to the results of the Annapolis tests, the United States Navy secured an emergency $1,000,000 congressional appropriation for the purchase of nickel, which was passed on September 17, 1890.[106] The ultimate effect of these tests was to induce the United States Navy to specify nickel steel as the basis for all orders of armor plate. Since Joseph Wharton, a director and major stockholder of the Bethlehem Iron Company, also possessed considerable holdings in the nickel ore business, Bethlehem was readily able to produce nickel steel.[107]

The production of armor plate was further revolutionized during the early 1890s by the introduction of the Harvey, or face hardening, process. This process involved the covering of low-carbon steel with charcoal and the heating of this mixture in furnaces, which imparted to the surface of the metal a tough veneer of great hardness. A variation of the centuries-old cementation process, it was the invention of an American industrialist, Hayward Augustus Harvey, who had managed since 1885 a small plant in Jersey City, New Jersey, which produced specially hardened steels for the production of tools such as files, cutlery and axes.[108] Harvey's business was a successful enterprise and in 1888 it was recapitalized and moved to a larger factory at Brill's Station in Newark, New Jersey. Seeking to expand the scope of the Harvey Steel Company's operations, its sales representative, H. S. Manning, contacted Captain William Folger, inspector of the naval ordnance factory at the Washington Navy Yard to attempt to arrange a demonstration of the hardening process.[109] After Folger expressed an initial interest, Harvey visited the factory to begin negotiations with Commodore Montgomery Sicard, Chief of Naval Ordnance. Experimental nickel steel armor plates were treated by Harvey's process at the Navy yard and bombarded in tests in June of 1890 and February of 1891. The hardened surface of the plate treated by the Harvey process broke up all projectiles on impact.[110] The success of these tests caused Capt. Folger to write: "These results are remarkable and indicate to the Department a probability that in this treatment has been found the means of producing the ideal armor plate; a hard front compounded with a tough back without any weld or other line of demarcation between the two."[111]

By March of 1891 a tentative agreement had been negotiated between the United States Navy and the Harvey Steel Company for the use of the face-hardening process. Due in large measure to intervention by the Navy Department, Harvey was granted a patent for his process and in the summer of 1891 Harvey and his superintendent, Joseph H. Dickson, erected at the request of the ordnance bureau a face-hardening furnace in the armor-finishing No. 3 Machine Shop of the Bethlehem Iron Company.[112] This furnace was soon placed into operation. After much experimentation, the Bethlehem Iron Company produced the first commercial face- hardened armor plate in America on July 30, 1892. This inch-thick Harveyed nickel steel armor plate was tested at Bethlehem's Redington proving ground. The plate successfully resisted the impact of five 250-pound armor piercing projectiles that were fired from an 8-inch gun. All of the projectiles broke apart and penetrated to a depth of only three inches.[113] The combination of nickel steel and face hardening produced what became the basis for almost all of the armor plate that was produced by both Bethlehem and Carnegie.

Despite the competition of the Carnegie-Phipps armor mill, the Bethlehem Iron Company continued to be a prosperous enterprise. During July of 1892 and March of 1893 Bethlehem received large orders from the United States Navy for gun forgings and armor plate respectively.[114] In order to increase their return on the capital investment of the forging plant, the directors of the Bethlehem Iron Company entered the international ordnance and armor market. In 1894 their efforts were rewarded when the Bethlehem Iron Company received a contract for 1,200 tons of armor plate from the Imperial Russian Navy.[115] By 1895 the forging and treatment plant of the Bethlehem plant had become internationally renowned as a leader in the production of ordnance forgings and armor plate. Lieutenant Colonel W. Hope, V.C., a British ordnance expert, visited the Bethlehem plant as a part of his worldwide tour of ordnance works and declared: "I consider the Bethlehem Gun Plant to be superior to any gun plant in the world."[116]

The production process by which armor plate was manufactured at the Bethlehem Iron Company is described in an unsigned manuscript dated January 29, 1895, that is contained in the Bethlehem Steel Historical Collection at the Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania. The emphasis of this manuscript is on the quality and efficiency of the Bethlehem forging plant equipment. It also states that the Bethlehem forging plant had an equal if not superior stature to the long established European ordnance and armor plants.

> Of the countries of the world to-day, England, France, Germany and the United States are foremost in the manufacturing of Armor and looking at the advancement made, results of competitive trials, and workmanship, one I think would place the United States at the head, although Krupp of Essen, Germany, is a firm with whom if another successfully competes gains a reputation that is of the highest quality.
>
> One reason for the high grade of armor manufactured is

that private firms are encouraged to develop and establish that business thus producing competition; and hence the best product, as well as the very exacting contract system in use. I have here a data sheet showing amount of data required. The requisites for certain tests must fall within certain limits, otherwise the work is rejected.

Probably no concern in this country, has made more progress or attempted bolder schemes, especially in the manufacture of armor, than the Bethlehem Iron Company, of Bethlehem, Pennsylvania. This concern has grown to what it is at the present time under the most clever management of one man. This one man is Mr. John Fritz to whom the title might well be given of "The Grand Old Man" of the American Engineering Profession." The armor plate department of this concern in production, manipulation and appliances, is on a par with the Vickers, John Brown, Cruesot and Krupp, as is proved in at least one of these (Production) by the result of the last most noted trial which took place in Europe and in which all the leading manufacturers took part. This trial was inaugurated by the Russian government and was for the purpose of determining the firm that should supply armor for some vessels of the Russian Navy. The contract was given to the Bethlehem Iron Company.

It will be impossible for me to take up the subject very broadly having had opportunity to visit but one works and for only one day. This day I spent at Bethlehem.

In the manufacture of any product, one of the principal items is costs, and location of plant affects this according to its relation to transportation, to the coal fields, and to the market for that product. If a plant is so situated that it can ship and freight by various routes, this produces competition among the different lines and hence a low freight rate. Being near the coal regions, the price of fuel is at a minimum. Near the sea board, the cost of freighting to the market is small. When one notices the location of Bethlehem, Pa., and the position of the plant in Bethlehem, one can see with what wise forethought Mr. Fritz selected it, for it is to him that the plant is so situated and that the Bethlehem Iron Company owes its rank among the leading manufacturers of armor plate at the present time. It is to him that the organization is so perfect. This seemingly not within the scope of this paper, is from my point of view; for is it not due to organization that the manufacture of any article is made a success? It is a very noticeable fact when passing through the works that each man has his business to attend to and that he "minds his own business and not others." The neatness of the yard, the order and system of the stock on hand, the marking of the stock, the arrangement of the buildings, such that the materials keep moving forward from one step to the next in such a way that the minimum of time is taken up with transportation, shipping department, laboratories and their inside detail, and many more points; all come under that one head organization.

In order that the explanation of the process may be made clearer, I will explain the press which forms these immense plates. The press is operated by means of hydraulic power, the high pressure 7000 lbs. to the square inch being obtained from hydraulic force pumps run by three single expansion vertical Corliss engines. To give one some idea of the immensity of these engines imagine a connecting the size of a man's body or a fly wheel 24 or 25 feet in diameter. To convey this water under such excessive pressure a special pipe was required. This pipe was 6" in diameter, came in sections of about ten feet, was turned out of solid steel forgings, and bored. At the ends of each section were flanges for joining. A point worthy of note is the fact that it was found necessary to stay this pipe very strongly on account of the vibratory effect produced by this heavy pressure.

The height of the press is about thirty-five feet. The main body was made from a solid steel forging and the cylinders bored. It was encased in a cast iron covering bolted as shown. Each of the rams was fifty and one-half inches in diameter, making the press capable of exerting a pressure under normal conditions of 14,543 gross tons or 29,764,520 pounds. The press of the Carnegie Company under normal conditions can exert a pressure of 12,000 gross tons or 29,120,000 pounds.

At the time I was visiting the works a conning tower was being made. What the pilot house is on an ordinary steamer the conning tower is to a man of war. In form it is cylindrical, the final dimensions of the tower in question being inside diameter 9', thickness of walls or metal 9¾", height 7'11", total weight a little over 52 tons. The ore is reduced by the usual blast furnace process and so from pig iron to steel by the open hearth. The open hearth being employed for the reasons of it being more easily manipulated, and on account of its producing the highest grade of steel. Three and one-fourth per cent. of nickel is added, this amount having been determined by trial and found to give the best results. Numerous furnaces are placed side by side the sinking pit running parallel to the furnaces directly in front. This pit is about 12' wide, and 15' deep and

200 or 300 feet long. Directly over it is a track upon which runs a ladle truck for receiving the metal from the furnaces. In the pit are placed the ingot moulds, that of the conning tower being 54 inches or 4'6" in diameter. These moulds are made of cast steel and are strengthened by collars. After the ingot is cast, the mould is so arranged that it can be moved over a plunger worked by hydraulic pressure. While a second plunger holds the ingot and mould from the top, the first is forced up from below for the purpose of solidifying the ingot and forcing out the gases at the top that if left in the metal would produce blow holes. There is a certain point in the ingot at which there collects the greater part of the deleterious matter which is termed the segregation point. This is usually very near the top of the ingot for the ingots are cast on end. The ingot is now removed from the mould, placed upon a flat car and transported to the reheating furnaces. These are Siemens Martin Regenerative Furnaces. To heat the ingot to the required temperature for forging under the press requires about one week's time. The ingot is then forged into an immensely thick disk of this form and a hole punched through it by means of cylindrical blocks 18" in diameter, first one being forced into the metal, then a second placed on that and forced down and so on until finally the first one placed in is forced through. What is termed a drift of this form is now passed through the piece from both sides to insure a perfect hole. The ingot was flattened for two reasons, to increase diameter and to facilitate punching. Through the hole formed is passed a mandrill which fits the hole and the piece placed under the press and lengthened in the direction of its axis from this form to this form. It is now ready for enlargement in diameter, this being done by placing on a bar. It was simply the finishing steps of the final enlargement that I witnessed. From the model I will be able to exhibit more clearly the handling of this 50 ton piece. The temperature at which the piece should have been forged was 2100° F., but owing to lack of time it was brought out at about 1800° or 1900° F. A great risk was run in doing this for on account of the size of the furnaces any enlargement of the piece would prevent it from reentering the furnace and as the Superintendent in charge expressed it, "It is $24,000 or nothing this time."

The temperature of the piece was determined by the color, it being a clear whitish yellow. By means of a porter bar and overhead cranes, it was removed from the furnace and placed under the press. As the porter bar was being removed, the bar was being placed within, the movements being governed by hydraulic cranes, managed by two men stationed at levers on one side of the press. On one end of the bar was placed a ratchet governed by one of the overhead cranes. This was used to turn the bar thus turning the piece. It took about twenty minutes for the piece to make one revolution. A man stationed on a raised platform positioned at one side of the press governed it, and by the aid of an automatic dial, governed the stroke of the press. This stroke could be either 1/16" or the total length of stroke which I think was about 7 or 8 feet. At each stroke from a 1/2 to an inch was compressed. During the revolution of the piece men were employed with long heavy bars chiseled on the end knocking off the scale and material that clung to the piece from resting on the bottom of the furnace. From time to time men measured the diameter of the piece at each end and also the thickness. The thickness being measured by callipers and the diameter by means of a right angle of wood; one end of one of the legs being placed against the inside face and the same leg being rubbed on outside opposite section. The metal being hot it scarred the wood and left a dimension mark. If the piece was found to be of less diameter on one side than the other a liner was placed under the bar on the side of least diameter. The total number of men employed about the press was 19, one superintendent, one assistant superintendent, one foreman, two men to control the two cranes, one to work the press, three engineers and 10 helpers. The time taken to work the piece down to the final forging was 4½ hours. The size of the bar used was 30" in diameter owing to the breaking of the 42" bar usually employed for that purpose. The tower is again reheated to 1350° F. and cooled in an immense vat of oil at the temperature of the air. This gives a certain amount of toughness and removes all strains after which it is removed, heated again to 1000° F. and subjected to the spraying process to harden. The spray is produced by numerous parallel vertical pipes with 1/8" holes drilled in the pipe 1" apart. These vertical pipes are arranged in a circular form and the piece placed within. In the treatment of the flat plates after being formed under the press they are subjected to the Harvey Process which is the heating to a very high degree of the plates or burning of carbon in the presence of the nickel steel excluding air. The plates are effected to about a depth of about 3 inches, the greater the length of time of heating the greater the depth in the place effected. After the carbonizing process, the plate is taken from

> the furnace and without removing the carbonaceous matter from the surface it is allowed to cool down to the proper temperature for chilling. During this cooling process, the carbonaceous material protects the hot super-carbonized surface from the air, and thus prevents the formation of scale which if present would prevent the subsequent hardening of the metal beneath it. For the purpose of ascertaining the temperature of the plate, small portions of the covering may be quickly removed and replaced without injurious effect. When by this method it is observed that the surface of the plate is at a dull cherry red, the carbon is quickly removed and the plate chilled. Great difficulty has been experienced in this chilling process due to the unequal warping of the plate. This is due to the uneven cooling which in turn is due to the non-uniformity of the flow of water over the surface of the plate. It is corrected by so forming the plate that it will warp to the correct form.
>
> The machine work on the plates is comparatively little. If a long forging is made this is sawn to lengths by immense circular rams made by the firm of Cruesot, France. These saws have specially tempered adjustable teeth which are about one inch across. For attaching the plates to the sides of a vessel long stud bolts are placed in the plates. The holes and thread for these are drilled and capped just before the Harvey process and bolts attached just after. These plates are attached to the vessel by means of the bolts which pass through a wooden backing and are fastened to the main frame of the vessel. The lookout hole in the conning tower is made by drilling tangent holes all about the piece to be removed. The methods employed in testing at the Bethlehem Plant are very thorough. Suppose a plate be required by the government to be tested. The plates are generally made a certain number at a time and say that one ingot makes four plates. The ingot is marked from the bottom up and every ingot numbered. The test pieces are removed from the plates as shown by illustration. These test pieces are numbered in this way; showing exactly from what plate the piece came, from what part of plate and ingot, and what numbered ingot. The results of this test are investigated and it is fair to suppose that if the plate showing the poorest results be sent to the proving grounds and that if it be accepted the others will show fully as good results.[117]

During the remainder of the 1890s the Bethlehem Iron Company continued to broaden the range of its forged products. The company dominated the market for large forgings for the electric power industry and it produced the field rings and rotor shafts for the large hydroelectric plants that were being built near Niagara Falls.[118] The Bethlehem Iron Company's technological expertise was also demonstrated by the forging of important components for the great Ferris wheel of the 1892-1893 Chicago World's Fair. The axle of the Ferris wheel was the largest steel forging to be manufactured up to that date.[119] The company also provided the crank shafts and propeller shafts for the engines of many of America's passenger liners and merchant ships.

The Bethlehem Iron Company also manufactured finished ordnance and gun forgings. Almost all of Bethlehem's orders for finished heavy ordnance were placed by foreign armed forces, while the United States continued its established practice of purchasing semi-finished forgings to be machined and finished at the Washington Naval Gun Factory and the Watervliet Arsenal. However, by 1900 both the United States Army and United States Navy had begun to purchase finished ordnance from the Bethlehem Iron Company, due to the rapid expansion in the number of both coast defense batteries and large warships. The Bethlehem Iron Company's No. 2 Machine Shop assumed the role of a major gun manufacturing facility and by 1900 it had become one of the largest and best-equipped machine shops in the world.

The increased capabilities of the Bethlehem Iron Company are highlighted by the 1904 testimony of Captain Edmund Pendleton, superintendent of the Washington Naval Gun Factory, before a Congressional Naval Appropriations Committee. The following selections from his testimony also highlight the interrelationships between Bethlehem and the Armed Services, and the dominant position that Bethlehem enjoyed over its only civilian domestic competitor in heavy ordnance production, the Midvale Steel Company of Philadelphia.

> Captain Pendleton: There are only two firms who can do anything. Those are the Midvale and the Bethlehem works. The Midvale concern has only just started. They are only doing the work from our detailed drawings. I have to furnish them with all the tools, jigs, etc. at a cost of $50,000 to $60,000.
> Mr. Butler: That is at Midvale?
> Captain Pendleton: Yes, sir. They do not know anything about the work. They send a man here, and we give him the details of the work. That man will stay in the shops day after day watching the work.
> Mr. Butler: After they learn, they will furnish their own tools?
> Captain Pendleton: No sir, we have built them. Of course, we charge them with the $60,000 but the government is paying for it in this $500,000.
> Mr. Butler: But the government does get this money back

by deducting it from the amount of the contract?
Captain Pendleton: That is right, but there is $40,000 or $50,000 worth of work that we are doing for them and crowding out our own work. They cannot do it.
Mr. Vreeland: Do I understand that the government does no casting whatever?
Captain Pendleton: No forging.
Mr. Vreeland: The Bethlehem Plant has done all of that?
Captain Pendleton: We have given the Bethlehem Company what they could do.
Mr. Loudenslager: Do I understand you to say that the Department has utilized all of the ability of the Bethlehem plant?
Captain Pendleton: Yes, sir, for the next three or four years.
Mr. Loudenslager: Has not the Bethlehem plant built some guns for other nations.
Captain Pendleton: They have built two ships, one for Turkey and one for some other nation.
Mr. Butler: Did the Bethlehem plant make the guns for these two ships?
Captain Pendleton: Yes, sir.
Mr. Vreeland: Are these private companies able to furnish all the forging the government needs?
Captain Pendleton: Yes, sir; because that is current work with a steel company.
Mr. Vreeland: There is no enlargement and expansion needed along that line?
Captain Pendleton: No, sir.
Mr. Vreeland: Do the private companies assemble the guns?
Captain Pendleton: None except the Bethlehem concern and now the Midvale concern is trying to. They are utilizing the machine shops they have and throwing out the other work, because this pays more.
Mr. Vreeland: Are they fixing their plants to completely furnish guns to the government?
Captain Pendleton: Yes, sir.[120]

The success of American warships during the short and victorious Spanish-American War served as great advertisement for the Bethlehem Iron Company since many of these vessels possessed armor, ordnance, propulsion machinery parts, and propeller shafts that had been manufactured by the company. The high regard in which the Bethlehem Iron Company was held by the United States Government can be discerned by the invitation of President William McKinley to Robert H. Sayre to take a prominent place on the official reviewing stand as the victorious United States Atlantic Squadron passed in a stately procession up the Hudson on August 20, 1898.[121]

The continued success of the Bethlehem Iron Company as a forging manufacturer convinced many of its principal shareholders that they could greatly increase their fortunes by selling out. On April 17, 1899, the directors organized the Bethlehem Steel Company.[122] This corporation was a holding company which immediately leased the properties of the Bethlehem Iron Company for a term of 999 years. The holding company was capitalized at $15,000,000 and it immediately issued 300,000 shares of stock each at a par value of $50.00. The directors of the holding company then offered the stockholders of the Bethlehem Iron Company, who were mainly themselves, the option to buy the shares of the holding company at a ratio of two shares for every one that they held of the Iron Company. The price of the Bethlehem Steel Company's stock was initially pegged at $1.00 per share. As a result of this offer, the principal shareholders of the Bethlehem Iron Company gained for a minimal cash outlay many additional shares of the Bethlehem Steel Company's stock. The entire transaction had been a gift from the Bethlehem Iron Company's capital resources to the stockholders.

The organization of the Bethlehem Steel Company marked the end of an era in the history of iron and steel making at Bethlehem. During the 1890s and early 1900s the principal figures in the company's early development retired or found other employment. This process began with the retirement of John Fritz in 1893, continued with the retirement of Robert H. Sayre in 1898, and concluded with the departure of Russell W. Davenport in 1902 to assume management control of the Cramp Shipbuilding Company in Philadelphia. However, even before Davenport's departure, ownership of the Bethlehem concern had changed hands.

In 1901 the British firm of Albert Vickers Sons and Maxim made an offer to buy control of Bethlehem as a means of entering the American ordnance and armor market.[123] Vickers was an immensely powerful conglomerate that produced armor-plate cannon and warships and held the principal patents for the self-acting machine gun. On May 28, 1901, Vickers offered to purchase all of Bethlehem's stock at a price of $22.50 per share.[124] The Vickers' offer was rejected and a counter offer of $24.00 per share from Charles M. Schwab, the president of the newly organized United States Steel Corporation, was instead accepted on May 30, 1901.[125] On August 15, the stockholders of the Bethlehem Iron Company voted to accept Schwab's offer. Each of the Bethlehem Iron Company's stockholders received a $1,000 bond for each twenty shares of Iron Company stock. The lease between the Iron Company and Steel Company was canceled and the Iron Company ceased to exist. In its place was a transformed Bethlehem Steel Company with a capitalization of $15,000,000 and complete operational control of the Bethlehem plant.[126]

Charles M. Schwab (1862-1939) was among the most brilliant and innovative steel makers in America. As the personal protégé of Andrew Carnegie, he had risen to become the president of Carnegie

Steel; he personally negotiated the merger of Carnegie Steel with the steel interests of J. P. Morgan to create the United States Steel Corporation, of which he became the first president.[127] Schwab purchased Bethlehem as an independent investment, but soon thought better of it and transferred control to United States Steel. However, when approached by a group of investors seeking to create a shipbuilding conglomerate, Schwab was able to repurchase the Bethlehem Steel Company for $7,246,000; he then transferred it to the newly organized United States Shipbuilding Company in return for a large interest in the new concern.[128] He also placed limits on the amount of control that the United States Shipbuilding Company could exercise over Bethlehem.

The United States Shipbuilding Company almost immediately began to experience financial difficulties. Although some of its shipyards were modern, efficient plants, many others were old, obsolete, and had almost no customers for their limited products.[129] In contrast, Bethlehem Steel Company continued to be a prosperous enterprise. Its forging plant with its large-capacity machine shop was regarded as the finest in America and was recognized as such in 1902 when it was chosen to build a 12,000-ton-forging press and pumping engine for its principal competition, the Homestead Plant of the United States Steel Corporation. To produce these great forging devices, Bethlehem produced the largest and heaviest steel castings yet made, some of which weighed more than 325,000 lbs.[130] During this period, the Bethlehem plant employed more than 9,461 workers and maintained a dominant position in the American ordnance and armor market, despite the increased competition that was brought about by the commencement of armor production by the Midvale Steel Company.[131] Between 1887 and 1904, Bethlehem produced 42,433 tons of armor plate for the United States Navy and an additional 12,500 tons for foreign purchasers. Carnegie, which was not a major factor in international sales, produced 46,605 tons of armor for the United States Navy. Bethlehem also produced more ordnance forgings than did the Midvale Steel Company.[132] Partly because Charles M. Schwab refused to allow a major proportion of Bethlehem's profits to be diverted to the parent corporation, the United States Shipbuilding Company failed in 1903. Despite a series of acrimonious law suits, Schwab was able to regain complete ownership of the Bethlehem Steel Company while at the same time salvaging the stronger of the United States Shipbuilding Company's shipyards. He combined these properties into the Bethlehem Steel Corporation, which was organized on December 10, 1904.

The new concern, of which Schwab immediately became president, was capitalized at $15,000,000. Its primary properties were the Bethlehem plant, the Harlin and Hollingsworth shipyard at Wilmington, Delaware, the Union Iron Works shipyard at San Francisco, California, Samuel L. Moore Son's Co. ship repair yard at Elizabethport, New Jersey, the Easton Shipbuilding Co. of Groton, Connecticut, the Crescent Shipyard at Elizabethport, New

Jersey, the Bath Iron Works Shipyard at Bath, Maine, the Hyde Windlass Company of Bath, Maine, and the Carteret Improvement Company, which controlled a large parcel of undeveloped land at Carteret, New Jersey.[133] Many of these shipyards proved to be of little value and by 1907, the Bath Iron Works, the Hyde Windlass Company and Eastern Shipbuilding Company had been sold and the Moore and Crescent Shipyards were consolidated. Despite these hasty divestitures, Schwab had created the basis of a greatly enlarged concern.

Even before the Bethlehem Steel Corporation was formally organized, Schwab stated his great plans for the company. As related by Robert Hessen in his biography, Steel Titan: "I intend to make Bethlehem the prize steel works of its class, not only in the United States, but in the entire world. In some respects, the Bethlehem Steel Company already holds first place. Its armor plate and ordnance shops are unsurpassed, its forging plant is nowhere excelled and its machine shop is equal to anything of its kind. Additions will be made to the plant rather than changes in the present process of methods of manufacture."[134]

Schwab planned to use the Bethlehem plant as the centerpiece for a large steelmaking concern that could compete successfully with the United States Steel Corporation, the presidency of which he had been forced to relinquish on August 4, 1903. Schwab believed that a steel company should be aggressively managed to continually seek ways to cut costs and prices, with a resulting increase in market share. This business philosophy clashed with the more conservative attitudes of Judge Elbert Gary, chairman of the board of the United States Steel Corporation, and in the ensuing power struggle, Schwab was forced out. Since Schwab had helped create United States Steel, he knew intimately that concern's strengths and weaknesses, and he planned to exploit the market opportunities that were created by United States Steel's conservative management policies whenever possible.[135]

Schwab realized that Bethlehem's continued dependence on military contracts was in the long term dangerous to the company's continued prosperity.[136] Despite the fact that Bethlehem continued to dominate the United States market for such items as ordnance forging, as is shown by the tables in Appendix B of this report, Schwab realized that the new corporation had to develop an expanded line of civilian products to cushion the shock of a sudden downturn in United States Government orders. Among his first acts, he ordered the installation of a crucible steel plant to produce high-quality alloy steels, and an open-hearth-steel rail mill.[137] Since the United States Steel Corporation did not possess an open-hearth rail mill, Schwab could charge a premium for the superior products of this new manufacturing facility and, since his competitor was loath to scrap its large investment in Bessemer-steel rail mills, Bethlehem faced little threat in this market from its much larger rival.[138]

Schwab also extended the range of the Bethlehem Steel Corporation's forging activities by adding a large-capacity drop-forging operation during 1905.[139] Bethlehem's drop-forge facility soon won a reputation for the high quality of its products and during the 1920s it pioneered in the production of forged cylinders for the newly developed radial air-cooled aircraft engines.[140] Until the 1980s the drop forge operations were a major profit center for Bethlehem Steel.

Schwab's boldest decision was to enter Bethlehem into the growing but fiercely competitive structural steel market. Once again, his knowledge of the strengths and weaknesses of the United States Steel Corporation was a decisive factor in his planning. Schwab knew that the Homestead Plant of the United States Steel Corporation was among the largest and most productive manufacturers of structural steel shapes in America and that it would be foolhardy for Bethlehem to compete directly with this colossus.[141] As he had done with the installation of an open hearth rail mill, Schwab planned to produce a superior product to fill a new market niche that was uncontested by United States Steel. He found this product in 1905 when he committed the Bethlehem Steel Corporation to the production of the continuously rolled wide-flange beam.[142]

The continuously rolled wide-flange beam was the development of immigrant British engineer Henry Grey (1846-1913). Grey's innovation was the development of a mill that could continuously roll wide-flange beams directly from ingots. His beams were wider, stronger, and less likely to bend. These beams were also much cheaper to produce because they could be continuously rolled as a single section, thus eliminating the high costs of riveting and other fabrication that were essential processes in the production of conventional beams.[143] Grey developed his revolutionary process at the Ironton Structural Steel Company of Duluth, Minnesota, and in 1902 he installed his first full-scale structural mill at Differdingen Steel Works in Luxembourg. Schwab learned of Grey's success while he served as president of United States Steel, but Judge Elbert Gary, the chairman of that vast concern, did not believe that Grey's beam could be mass produced and thus rejected it. As a consequence, Schwab was able to secure the rights to Grey's invention for Bethlehem in 1908.[144]

Schwab's decision was a bold move and a potentially dangerous financial gamble for the Bethlehem Steel Corporation. An investment of almost $5,000,000 would be needed to build the new division of the Bethlehem plant that would produce the Grey beam.[145] During the next year Schwab attempted to raise this sum from a variety of sources and by July of 1908 the Saucon Division of the Bethlehem plant with its open-hearth furnaces and structural mill was placed in full operation.[146] This achievement was largely the responsibility of Eugene Grace (1876-1960), who became Schwab's chief protégé and his eventual successor as the head of Bethlehem Steel. However, despite the successful production of the Grey beam, this new product initially found few buyers and Schwab was forced to turn to Bethlehem's forging operations for financial salvation.

Since domestic orders for ordnance and armor plate were flat, Schwab hoped to increase foreign sales of military hardware. Bethlehem had been, for more than a decade, a major factor in the international arms and armor-plate market and was a charter member, along with Krupp, Schneiders, and Vickers-Armstrong, of the international armor-plate cartel, the Harvey United Steel Company, Ltd.[147] The Harvey United Steel Company was a patent pool which held almost all of the important patents concerning armor-plate production; it also served as an informal means by which its members divided up the international armor-plate market. Schwab sought to increase Bethlehem's share of this lucrative trade so that he could gain the funding needed to subsidize the operation of the new Grey Mill. Archibald Johnston (1865-1947), who served as Bethlehem's vice president of sales and who had long been associated with the forging operation, was sent to Europe to negotiate with the other members of the Harvey United Steel Corporation. Johnston was successful and by 1908, Bethlehem's share of the international armor-plate market had risen to a level of $2,000,000 annually.[148]

Due in large measure to these increased foreign military sales, Bethlehem was able to continue marketing the Grey beam. By 1909 the Grey beam had entered the marketplace, insuring the success of Schwab's efforts to diversify Bethlehem's product line. By 1914 sales of structural steel were double the annual total value of Bethlehem's forging sales. At the same time, the United States Government began to increase its orders for armor plate and ordnance forgings. In 1909, Bethlehem received an order for 7731 tons of armor from the United States Navy valued at $2,300,000, and in 1910 it received its largest single order to date for military products when Argentina purchased ordnance, shells, and armor valued at more than $10,000,000.[149] Orders such as these continued to keep the forging operations at Bethlehem in full operation. The great amount of military materials that had been produced by Bethlehem up to this time was summarized in a list prepared in 1912 for a company publication, <u>Historical Sketch of the Development of the Bethlehem Steel Company and the Bethlehem Steel Corporation</u> which is reprinted as Appendix C of this study.

The profits of the military contracts and civilian sales of heavy forgings continued to be a major financial support of the Bethlehem Steel Corporation and enabled Schwab to survive the deleterious effects of a serious strike that took place in 1910.[150] To further expand the Bethlehem Steel Corporation's military products and shipbuilding production capacity, Schwab negotiated the purchase of the Fore River Shipbuilding Company at Quincy, Massachusetts in 1913.[151]

The outbreak of World War I in August, 1914, was a windfall for the Bethlehem Steel Corporation. Possessing the largest capacity forging plant in America, and already playing a major role as an international supplier of military hardware, the Bethlehem Steel Corporation was in a unique position to fill orders from the warring powers. It was the first American firm to receive war materials orders from the allied powers of Britain and France and by December of 1914, Bethlehem had received over $50,000,000 in ordnance orders from these nations, and a total order of $135,000,000 for items such as shells and submarines.[152] This sales bonanza was particularly welcome since Bethlehem had not paid dividends since 1906 due to Schwab's consistent policy of re-investing profits in capital expansion of the Bethlehem plant's production capacity. The influx of war orders also spurred a dramatic rise in the price of Bethlehem's common stock from a level of $30 per share in 1913 to $600 per share in January of 1915, and to an eventual peak at $700 in 1916.[153]

To fill the flood of British and French orders, Bethlehem embarked on a rapid expansion of its production facilities. In 1913 the total work force of the plant was 9,000 men. By the end of 1914 this number had grown to 24,567 employees of whom more than 2,000 were employed on plant construction alone.[154] Over $25,000,000 was spent on expansion, including the completion of a large, four-story addition to No. 2 Machine Shop, which was the company's primary heavy-ordnance finishing facility. By the end of 1914 the products of Bethlehem's forging operation were being utilized by many other parts of the plant to produce military products, such as No. 3 Machine Shop, which specialized in the manufacture of field artillery caissons, and No. 4 Machine Shop which became Bethlehem's primary producer of field guns.[155] Other shops combined to turn out more than 2,000 shells per hour, which were filled with high explosives at the new loading facilities located at the company's Redington proving grounds almost two miles to the west of the main plant.[156] By the beginning of 1915, Bethlehem had on its books more than $300,000,000 in military products orders. The rapid expansion of Bethlehem military production can best be illustrated by noting that between March and August of 1914 Bethlehem manufactured a combined total of 250 gun mounts, caissons, and artillery tubes. However, between August and December of 1914 it produced over 5,832 completely finished field guns and caisson sets. Shell production rose from a mere 18,620 during the March-to-August period to a staggering total of 12,792,963 during the next six months.[157]

Despite a disastrous fire that destroyed No. 6 Machine Shop in 1915, and temporarily decreased military production, the output of war materials from the Bethlehem plant became ever greater during 1915 and 1916. When the United States entered World War I in 1917, the importance of Bethlehem Steel as a military contractor rose to new heights. By 1918 over 35,000 workers were employed at the Bethlehem plant.[158] In total, by 1919 the plant produced 60% of the finished guns ordered by the United States, 65% of all American gun forgings ordered and 40% of this nation's artillery shell orders.[159] In addition, forges and machine shops supplied the French armed forces with semi-finished gun tubes for more than 21,000 field pieces. For Britain and France combined it supplied 65,000,000 pounds of forged military products, 70,000,000 pounds of armor plate and an incredible total of 1,100,000,000 pounds of steel for shells, and 20,100,000 rounds of artillery ammunition.[160] Between April of 1917 and the Armistice in November of 1918, Bethlehem produced more than 65% of the total number of finished artillery pieces that were manufactured by all of the allied nations. In order to achieve these miracles of productivity, the company had expended more than $102,000,000 for the construction of new facilities at the Bethlehem plant.

Among the most important of these new facilities was the development of a new forging complex in the Saucon Division of the Bethlehem plant. The impetus for this expansion was provided by the plans of the United States Navy to build the largest fleet of battleships in the world. These ships would be faster and more heavily armed and armored than those of rival navies. Great 16-inch 45-caliber guns would give them unprecedented offensive might.[161] Since these guns would be both larger and heavier than the 12-inch and 14-inch guns that Bethlehem had previously produced, new facilities would have to be constructed to insure their manufacture. These new facilities were constructed in the Saucon Division of the Bethlehem plant, one-half mile to the east of No. 3 High House. The first of these facilities, the No. 5 High House and No. 8 Machine Shop facilities, were placed in operation on November 15, 1918. No. 5 High House was a particularly impressive achievement. This structure possessed more than twice the interior volume of No. 3 High House; it was more than 239 feet in height with a massive electrically powered traveling crane that was capable of lifting more than 225 tons, the largest of its type to have been built in America.[162]

The enormous profits that the Bethlehem Steel Corporation earned during World War I enabled Charles M. Schwab to undertake an acquisition program that included the purchase of many of the remaining independent American steelmakers. The first, and in many ways most notable, of these acquisitions was the purchase of the Pennsylvania Steel Company and its subsidiary, the Maryland Steel Company, on February 16, 1916.[163] During 1916 Bethlehem also purchased the American Iron and Steel Company of Lebanon, Pennsylvania, a firm that held a large share of the American nut and bolt market, and the large Cornwall, Pennsylvania, iron mines of the Lackawanna Iron and Steel Company.[164] In 1919, Bethlehem purchased control of the Midvale Steel Company in order to acquire its subsidiary, the Cambria Steel Company at Johnstown, Pennsylvania. Fearing antitrust action, Bethlehem did not purchase Midvale's Philadelphia plant, which became the focal point of a reorganized and independent Midvale concern.[165] Bethlehem's final major purchase occurred on October 9, 1922, when it gained control of the Lackawanna Steel Company with its massive plant located at Lackawanna near Buffalo, New York.[166]

The completion of this massive acquisition program enabled Bethlehem to become a well-rounded competitor to the United States Steel Corporation in most areas of commercial steel production. Between 1905 and 1925 its steel-making capacity expanded from an ingot capacity of 190,000 tons annually to 7,000,000 tons annually.[167] Equally dramatic was the rapid decline in the amount of the Bethlehem Steel Corporation's military related production. In 1905 approximately 92% of the corporation's annual production was devoted to military productions. By 1925 less than 5% of the Bethlehem Steel Corporation's products consisted of such items.[168]

The effect of this expansion and switch over to commercial steel production had a dramatic impact on the development of the Bethlehem plant. The increasing popularity of the Grey beam and the other commercial products absorbed almost all of the facility's productive capacity. This reorientation is highlighted in the following passages from a January 3, 1924, memo sent by Archibald Johnston to Bethlehem President Eugene Grace:

> Ordnance vs. Structural
>
> The Bethlehem Steel Company (Bethlehem Plant) which prior to the outbreak of the great war in Europe was the largest steel making plant in the United States and which during the war devoted its entire effort to the production of guns, munitions and war materials, has now practically completed the change of its property to the manufacture of commercial steel and steel products. It has converted its entire war material plant except a portion of the ordnance making capacity, which is held for emergency use. At the present time less than two percent of the total property and plant investment is devoted to ordnance. The amount of cash investment now devoted to ordnance is actually less than it was before the war started in Europe in 1914. The Company has literally turned from the manufacture of guns to plowshares.
>
> The actual conversion of the Company's ordnance manufacturing facilities from war to peace conditions is well illustrated by a comparison of the October 1918 production of three typical ordnance shops with the production of same shape in 1923:
>
> No. 5 Machine Shop - Now No. 3 Structural Fabricating Shop
> October, 1918, Produced 535 limbers and ca[illegible].lbs.
> October, 1923, Produced and shipped fabricated
> structural material . . . . .3,010,000 lbs.

No. 1 Projectile Forge
October, 1918, Forged shrapnel and shells, weighing 4,560,000 lbs.
October, 1923, Produced 1640 steel truck wheels, weighing 298,000

No. 1 Projectile Machine Shop - No Central Tool Shop
October, 1918, Machined shells 71,000 pieces, 125,000 lbs.
October, 1923, Manufactured commercial and manufacturing tools, 48,433 pieces . . . 229,159 lbs.

> It is notable that whereas in 1918 the material produced was made up largely of large numbers of articles <u>exactly alike</u>, the present production includes thousands of different articles. In the No. 1 Projectile Shop noted above, the production in 1918 was of machined shells, all practically alike, while at present the production of that shop includes milling cutters, punches, jigs, rivet sets, gauges, the better grade of highly finished machine shops products. In general, the policy of the Company is to produce an ever more diversified line of products - to the end that the falling off of demand in <u>one line</u> will be compensated by capacity in <u>other lines</u>.[169]

Coupled with the Bethlehem Steel Corporation's policy of switching from military products to commercial steel products as the basis for its future manufacturing activities was the devastating impact of the Washington Naval Conference of 1922. The treaty produced by this diplomatic meeting resulted in the virtual cessation of battleship construction in the United States and a drastic reduction in the building of other armored warships.[170]

The signing of the Washington Treaty brought about an abrupt halt to production on February 9, 1922. Armor-plate production at Bethlehem's forging facilities ceased during February of 1922. At that time the forging and treatment facilities were working at their full capacities, producing 1120 tons of battleship armor.[171] All phases of operations on all unfinished armor plates were immediately halted. The plates that were the closest to completion were shipped to United States Navy storage depots and all others were scrapped. The Bethlehem Steel Corporation received a large settlement from the United States Navy for the losses that it incurred from the abrupt cancelling of these contracts. No further armor contracts were received until December of 1930.[172]

The halting of armor and heavy gun production at Bethlehem brought about important alterations to the operation of its forging and treatment facilities in order to increase the amount of commercial forging work that could be completed. The furnaces of No. 2 Treatment Shop were changed from producer gas to coke and blast gas as a fuel source. To provide work for No. 3 Machine Shop, (the armor-finishing machine shop), various expedients were developed including the repair of 59 Lehigh Valley Railroad locomotives between 1922 and 1924, and the machining of large parts for coal-pulverizing machinery manufacturers. However, this sporadic work was not sufficient to maintain the facilities of No. 3 Machine Shop in full operating condition and, before armor plate production could restart in 1931, the machinery of the shop had to be almost entirely rebuilt.

At the time of the cessation of armor-plate production in 1922, Bethlehem's forging operations centered on No. 1 Press Forge Shop, No. 2 Heat Treatment Shop, and No. 3 Machine Shop. No. 1 Press Forge Shop employed 50 men and contained a 14,000-ton-force hydraulic forging press, a 6,000-ton-force hydraulic bending press, two 150-ton capacity cranes, five hearth furnaces and six carbottom furnaces. No. 2 Treatment Shop had a work force of 60 men, and this facility was built around ten producer-gas-fired carbottom furnaces, and four soft coal bung-type furnaces. This shop also contained a covered water spray quench tank, and two cranes of 100 and 75 tons respective lifting capacity. No. 3 Machine Shop, which was primarily devoted to the finishing of armor plate, was the most labor intensive of these facilities with 150 men being employed there. No. 3 Machine Shop contained four rotary saws, two horizontal boring and milling machines, four column drills, two side planers, one pit planer, four cranes, and a large cast iron assembly floor. Attached to No. 3 Machine Shop was the tool room which contained three table planers, one cutting-off machine, two large grinders and an unspecified number of small drill presses. The total production capacity of this complex was rated at 1120 tons of armor plate per month.[174]

During the 1920s the Bethlehem Steel Corporation also temporarily ceased the production of heavy ordnance. However, the smaller hydraulic forging press of No. 1 Forge Shop was utilized to produce commercial forgings.[175]

When the manufacture of armor plate resumed in 1931, almost all of Bethlehem's armor-plate production facilities were in poor condition due to an almost nine-year period of virtual inactivity. As a result of this deterioration, the rate of armor-plate production capacity of this facility was reduced to only 500 tons per month.[176] This capacity was soon expanded due in large measure to the gradual buildup of the United States Navy in response to what was perceived as a growing threat from the Japanese fleet.

The United States Navy completed the design work on a new class of battleships (The USS North Carolina and the USS Washington) in 1937, and from that point onward a steadily accelerating program of new ship construction gained renewed momentum.[177]

In response to this increase in United States naval construction with its corresponding rise in government orders for ordnance, armor plate, and propulsion machinery parts, the Bethlehem Steel Corporation began to expand and upgrade its forging and treatment operations. These improvements continued until the tremendous production demands of World War II caused a much greater expansion of Bethlehem's forging and treatment facilities. A complete description of this expansion is contained in Appendix B of this report.

Despite this massive campaign of improvements, it was not until December of 1939 that the production of armor plate at the Bethlehem plant reached its World War I figure of 1120 tons per month. However, by October of 1942, the pressure of war-time demands and the completion of much of the expansion program had increased this figure to 3166 tons of armor per month.[178] A corresponding rise in the number of men employed in armor production took place between 1931 and 1942. In 1931 50 men were employed at No. 1 Forge Shop, 40 men at No. 2 Treatment Shop, and 30 men at No. 3 Machine Shop, for a total of 120 men directly involved in armor production. By the end of 1942, 175 men were employed at No. 1 Forge Shop, 400 men at No. 2 Treatment Shop, 350 men at No. 3 Machine Shop, for a total of 1,025 workers who were employed in armor production.[179] It is remarkable that this expansion was maintained even though the Bethlehem Plant was extensively damaged by a flash flood of the Lehigh River on May 12, 1942.[180] Gun production at Bethlehem was also increased by the opening of No. 2 Forge Shop in August of 1942 at the Saucon Division of the Bethlehem plant. This shop took over much of the production of heavy guns; its operations were highlighted in a major article that appeared in the August 25, 1942, issue of Life magazine.[181] The completion of this facility was the culmination of a plan that had been halted by the end of World War I.

The naval expansion of the 1930s and the pressures of wartime production brought great changes to the structures of the original Bethlehem forging plant. No. 1 Press Forge was extended to the east and joined to No. 1 Forge Shop and No. 3 Machine Shop. No. 2 Treatment Shop was also greatly enlarged. The full extent of this expansion can be discerned by the data included in Appendix B which contains in great detail the upgrading of the treatment and forging facilities of the Bethlehem plant, including the construction of additional treatment facilities in the Saucon Division.

Although it did not have the dominant position that it had held during World War I, the Bethlehem plant became a major contributor to America's defense during World War II. By 1943 over 33,000 workers were employed at the Bethlehem plant.[182] The high quality of the firm's products was continually evident, particularly in the field of naval ordnance.[183] A highlight of Bethlehem's World War II ordnance work was the production of the 16-inch 50-calibre guns that comprised the main armament of the United States Navy's Iowa-class battleships.[184] These massive guns were to provide exemplary service in four wars; Bethlehem was the sole supplier of this most powerful of all the United States Navy's cannons. The overall productivity of Bethlehem was prodigious. Peak production at the armor ordnance and shell facilities was reached during the autumn of 1944 when one million 75- and 9-millimeter shells, 732,000 rough-shell forgings, and 21,200 tons of gun forgings and finished guns were produced. The drop forge facility also supplied 83 % of America's needs for airplane engine cylinders.[185]

World War II marked the end of an era for the Bethlehem Steel Corporation. During that conflict it had been one of America's largest defense contractors. Its yards had built over 1121 merchant and naval vessels and repaired an additional 38,000 ships, and in 1944 it had made more than 13,000,000 tons of raw steel.[186] However, this massive production meant that the United States armed forces had many vessels that were suddenly surplus to its needs after the defeat of Japan in 1945. For more than a decade production of almost all major warships ceased; in the case of battleships this halt meant the permanent cancellation of all vessels of this type that were under construction. This halt to heavily armored warship construction virtually shut down Bethlehem's armor plant in 1946 and with the exception of a single experimental plate that was produced for the United States Navy in 1956 no forged armor was made at this facility.[187] Since the 1950s rolled high-yield steel plate has replaced forged armor as the primary protective material employed in United States warships.

The ending of armor plate production made the great 14,000-ton-force hydraulic forging press and its associated steam pumping engine largely redundant. In 1952 it was scrapped and the No. 1 Forge Shop was converted to a relining facility for hot-metal transfer railroad cars, a function that it has continued through 1990.[188] Many of the functions of the 14,000-ton-force press were taken over by a 8,000-ton-force hydraulic forging press which had been installed in the No. 2 Forge Shop during 1939-1940. Manufactured by the United Engineering Company, this press was purchased with funds provided by the United States Navy. In 1981-1982 it was modernized and upgraded to a 12,000-ton-force forging capacity.[189]

Bethlehem continued to be a major supplier of semi-finished gun forgings throughout the 1950s and 1960s with its primary products being 90mm tubes for tanks and 175mm tubes for long range artillery. Production of gun forgings at Bethlehem ceased during 1968 but was resumed during 1987-1989 when 120mm tank gun forgings were made for the United States Arsenal at Watervliet, New York.[190]

During the 1950s Bethlehem developed a new line of forging products as the result of the construction of nuclear-powered warships and power plants. Bethlehem was also able to gain a major competitive advantage through the development of the vacuum degassing method of casting steel forging ingots. In the vacuum degassing process molten steel is poured from a furnace ladle into a smaller or pony ladle and from there it is drained into an ingot mold that is contained in a vacuum chamber. As the molten steel passes into the vacuum of the chamber it breaks up into tiny droplets, allowing most of the hydrogen and oxygen gases that it contains to escape. By the time it reaches the mold the steel is largely free from gas bubbles and as it cools it assumes a largely stress-free internal structure.[191] Bethlehem has used the vacuum degassing process since 1956 and combined with its existing heavy forging capacity it has enabled the company to dominate the United States market for heavy forgings such as turbine rotors which are subject to severe internal stresses. Bethlehem has produced vacuum-degassed forgings that have weighed more than 500,000 lbs.

Bethlehem has emerged as the sole remaining super-heavy-forging plant in the United States. Its two former rivals, Midvale and Homestead, have ceased operation. The Midvale Steel Company merged with the Heppenstal Corporation of Pittsburgh in 1970 and by 1977 the plant at Philadelphia was shut down.[192] The forging operations at the Homestead Plant of the United States Steel Corporation functioned until the autumn of 1984.[193]

During 1990 many of the original buildings of the BethForge Division of the Bethlehem Steel Corporation remain intact. The No. 2 Treatment Shop continues in its original function while No. 3 High House has been placed on a semi-active status. In 1990 a joint venture was concluded between the Bethlehem Steel Corporation and French corporation Chavanne-Ketin for the production of cast iron rolls for steel rolling mills.[194] It is not known to what extent the development of this joint venture will have an impact on the historic buildings and machinery of the BethForge Division of the Bethlehem plant of the Bethlehem Steel Corporation.

In conclusion, the forging operations of the Bethlehem Steel Corporation's Bethlehem plant continue to play a leading role in the development of the super-heavy-steel-forging industry in the United States. The extant buildings and early machinery of this manufacturing complex form an outstanding monument to the growth of the American defense industry.

Notes

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6. Stapleton, Transfer of Industrial Technology, op. cit., 176. See also Sayenga, "Untryed Business," op. cit., 122; and Bartholomew, "Anthracite Iron," op. cit., 28.
7. Bartholomew and Metz, The Anthracite Iron Industry of the Lehigh Valley, op. cit., 20-21. See also Samuel Thomas, Transactions of the American Institute of Mining Engineers, Vol. XXIX, 1899.
8. Walter Johnson, Notes on the Use of Anthracite in the Manufacture of Iron, Boston, Massachusetts: C.C. Little and John Brown, 12. See also Stapleton, The Transfer of Early Industrial Technologies, op. cit., 182-184,; and Craig L. Bartholomew, "Anthracite Iron," op. cit., 36-37.
9. Sayenga, "Untryed Business," op. cit., 123. See also Waltman, "Influence of the Lehigh Canal," 88-91; and Anthony J. Bryski, "The Lehigh Canal and Its Effects on the Region Through Which it Passed, 1818-1873," (unpublished Ph.D. dissertation, New York University, 1957).
10. Ibid., 684. See also Craig L. Bartholomew, "Anthracite Iron Making," op. cit., 139-141.
11. Robert P. Archer, The History of the Lehigh Valley Railroad, Berkeley, California: Howell North Books, 1978, 27. See also Jules I. Bogen, The Anthracite Railroads, New York, N.Y.: Ronald Press, 1927, 110 and Randolph L. Kulp (ed.), Railroads in the Lehigh River Valley. Allentown, Pa.: Lehigh Valley Chapter of the National Railroad Historical Society, 1962, 41.
12. The business career of Asa Packer is chronicled by Milton C. Stuart, Asa Packer 1805-1879, New York, N.Y.: American Newcomen Society, 1938. See also Lawrence H. Gipson and Robert C. Cole, Asa Packer, Bethlehem, Pa.: Lehigh University 1966 and W. Ross Yates, Asa Packer: A Perspective, Bethlehem, Pa.: Lehigh University, 1983.
13. Biographical information on Robert H. Sayre is contained in Lance E. Metz, Robert H. Sayre, Engineer, Entrepreneur and Humanist, Easton, Pa.: Center for Canal History and Technology, 1985 and in Robert Sayre's personal diaries 1850-1907 which are contained in the collections of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
14. Robert Archer, A History of the Lehigh Valley Railroad, op. cit., 32.
15. The Lackawanna Iron and Coal Company is chronicled in W. David Lewis "The Early History of the Lackawanna Iron and Coal Company: A Study in Technological Adaptation," Pennsylvania Magazine of History and Biography, Vol. XCVI, No. 4, October 1972. The involvement of Moses Taylor in this enterprise and the Delaware, Lackawanna and Western Railroad is chronicled in Daniel J. Hodas, The Business Career of Moses Taylor, New York, N.Y.: New York University Press, 1976 and Burton W. Folsom, Urban Capitalists, Baltimore, Maryland: Johns Hopkins University Press, 1987.
16. W. Bruce Drinkhouse, The Bethlehem Steel Corporation: A History from Origin to World War I, Easton, Pa.: The Northampton County Historical and Genealogical Society, 1964, 4. See also Arundel Cotter, The Story of Bethlehem Steel, New York, N.Y.: Moody Magazine and Book Co., 1916, 2 and W. Ross Yates (ed.), Bethlehem of Pennsylvania:

The Golden Years, Bethlehem, Pa.: Bethlehem Book Committee, 1976, 28-30.

17. Yates, Bethlehem of Pennsylvania, op. cit., 30-31. See also Lance E. Metz, John Pritz: His Role in the Development of the American Iron and Steel Industry and His Legacy to the Bethlehem Community, Easton, Pa.: Center for Canal History and Technology, 1987, 14-15.
18. Metz, John Pritz, op. cit., 16. See also Yates, Bethlehem of Pennsylvania, op. cit., 30. See also An Historical Sketch of the Development of the Bethlehem Steel Company and the Bethlehem Steel Corporation, Bethlehem, Pa., 1912, 3.
19. Minutes of the Meeting of the Board of the Bethlehem Rolling Mills and Iron Company, June 14, 1860. (Xerox copies of original minute book on deposit at the Hagley Museum and Library, Wilmington, Delaware, and the Hugh Moore Historical Park and Museums, Inc., Easton, Pennsylvania)
20. John Fritz, The Autobiography of John Pritz, New York, N.Y.: John Wiley and Sons, 1912, 91-134 (actually the works of the Cambria Iron Company were under the control of the firm of Wood Morrell and Company).
21. Lance E. Metz and Donald Sayenga, "John Pritz and the Development of the Three-High Rail Mill 1855-1863," Papers of the 1989 SIA Conference, Quebec City, Canada, 11-14.
22. Ibid.; 18.
23. Agreement between John Pritz and the Bethlehem Rolling Mill and Iron Company July 10, 1860, contained in the Pritz Collection of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
24. Bartholomew and Metz, Anthracite Iron Industry of the Lehigh Valley, op. cit., 179. See also W. Bruce Drinkhouse, Bethlehem Steel Corporation: A History from Origin to World War I, Easton, Pa.: Northampton County Historical and Genealogical Society, 1969, 4-5, and Historical Sketch of the Development of Bethlehem Steel Company and Bethlehem Steel Corporation, Bethlehem, Pa.: Bethlehem Steel Corporation, 1912, 3.
25. R.D. Billinger, "Beginnings of Bethlehem Iron and Steel," Bulletin of the Commonwealth of Pennsylvania Department of Internal Affairs, Vol. 20, Peb. 1953, 5. See also Bartholomew and Metz, The Anthracite Iron Industry of the Lehigh Valley, op. cit., 179 and the undated memo of important dates in the history of the Bethlehem Iron Company compiled by the company's secretary, Abraham Schropp, contained in the Pritz Collection. Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
26. W. Ross Yates, Joseph Wharton, Quaker Industrial Pioneer, Bethlehem, Pa.: Lehigh University Press, 1987, 140-144.
27. Bartholomew and Metz, Anthracite Iron Industry of the Lehigh Valley, op. cit., 180.
28. Bartholomew and Metz, Anthracite Iron Industry of the Lehigh Valley, op. cit., 179-180. See also Drinkhouse, Bethlehem Steel Corporation, op. cit., 5, and minutes of the meetings of the board of the Bethlehem Iron Company, April 8 and September 23, 1868. (Xerox copies of original minute book on deposit at Hagley Museum and Library, Wilmington, Delaware and the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.)
29. Yatea, Bethlehem of Pennsylvania, op. cit. 115.
30. Yates, Joseph Wharton, op. cit., 146.
31. Donald Sayenga, "Canals, Converters and Cheap Steel," Canal History and Technology Proceedings, Vol. VIII, 1989, 94-95.
32. John Pritz, Autobiography, op. cit., 150. See also Jeanne McHugh, Alexander Holley and the Makers of Steel, Baltimore, Maryland: John Hopkins University Press, 1980, John Bergenthal, "The Troy Steel Company and its Predecessors" (an unpublished 1987 manuscript that is an enlargement of a senior thesis at Rennselaer Polytechnic Institute, Troy, N.Y.) and Phillip Bishop.
33. Metz and Sayenga, The Role of John Fritz, op. cit., 19.
34. McHugh, Alexander Holley, op. cit., 93-103.
35. U.S. Patent No. 17,389 granted to Robert F. Mushet, May 26, 1867. See also E.F. Longe, Bessemer, Goronsson and Mushet, Manchester, England, 1913.
36. The entries in Robert H. Sayre's diaries for October of 1865 contain many references to meetings between Sayre, Fritz and professors of chemistry, metallurgists and other experts who were working to perfect the Bessemer process.
37. McHugh, Alexander Holley, op. cit., 301. See also Quincy Bent, "History of the Steelton Plant" (unpublished undated manuscript contained in the Bethlehem Steel Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pa. Quincy Bent was the son of Luther Bent, former general manager of the plant and the grandson of Samuel Felton, the first president of the Pennsylvania Steel Company. See also Mark Reuter, Sparrows Point: Making Steel -- the Rise and Ruin of American Industrial Might, New York, N.Y.: Summit Books, 1988, 17-34.
38. Diary of 1868 European trip in the Fritz Collection at the Hugh Moore Historical Park and Museums, Inc., Easton, Pa. This journey was compiled by George Fritz, who accompanied his brother, E.P. Wilbur of the Lehigh Valley Railroad, Harry Packer, the son of Asa, and Abram S. Hewitt of the Trenton Iron Company on this fact-finding tour.
39. McHugh, Alexander Holley, op. cit., 241-244. See also John Pritz, Autobiography, 152-158.

40. "Unpublished list of historical dates of the Bethlehem Iron Company" compiled by Abraham S. Schrapp, contained in the John Fritz Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
41. Robert W. Hunt, "A History of Bessemer Manufacture in America," The Transactions of the American Institute of Mining Engineers, Vol. 5 (1876-1877), 212-213.
42. Guide-Book of the Lehigh Valley Railroad and Its Several Branches and Connections with an Account Descriptive and Historical of the Places Along their route: Including Also History of the Company from its First Organization and Interesting Facts Concerning the Origin and Growth of the Coal and Iron Trade in the Lehigh and Wyoming Regions, Philadelphia, Pa.: J. B. Lippincott & Co., 1873, 42-43.
43. Frank H. Taylor, Autumn Leaves Upon the Lehigh: Picturesque and Industrial Scenes Along the Line of the Lehigh Valley Railroad, Philadelphia, Pa.: James W. Nagle, 8-9.
44. McHugh, Alexander Holley, op. cit., 242.
45. Handwritten note chart listing the production tonnage of eleven American steel plants, one of a series of similar items in the Robert H. Sayre Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pa. It should be noted that the Edgar Thomson works had only begun production in 1875.
46. Kenneth Warren, The American Steel Industry: A Geographical Interpretation, Oxford, Great Britain: Clarendon Press, 1973, 96-103. After 1883 the Bethlehem Iron Company was forced to increasingly depend on the Juraga mines in Cuba. It operated these mines as a partnership with the Pennsylvania Steel Company.
47. Ibid.
48. Ibid.
49. Ibid.
50. The demise of Troy Steel is examined in John Bergenthal's previously cited paper.
51. Thomas J. Misa, "Science Technology and Industrial Structure: Steel Making in America 1870-1925" (unpublished Ph.D. Dissertation, University of Pennsylvania, 1987, 64-65).
52. Taylor Peck, Round Shot to Rockets, A History of the Washington Navy Yard and United States Naval Gun Factory, Annapolis, Maryland: United States Naval Institute Press, 1949, 171-174. See also Harold and Margaret Sprout, The Rise of American Naval Power 1776-1918, Princeton, N.J.: Princeton University Press, 1939, 165-183 and Frank M. Bennett, The Steam Navy of the United States, Pittsburgh, Pa.: W. T. Nicholson, 1896, 474-553.
53. Peck, Round Shot to Rockets, op. cit., 172. See also Benjamin Franklin Cooling, The Gray Steel and Blue Water Navy: The Formative Years of America's Military Industrial Complex 1887-1917, op cit., 16-17, and John D. Alden, The American Steel Navy, Annapolis, Maryland: United States Naval Institute Press, 1972, 3-4.
54. Dean C. Allard, "The Influence of the United States Navy Upon the American Steel Industry, 1880-1990," (unpublished Ph.D. Dissertation, Georgetown University, 1959, 15). See also Sprout, The Rise of American Naval Power, op. cit., 186-87, and Cooling, Gray Steel and Blue Water Navy, op. cit., 27-30.
55. "Report of the Naval Advisory Board," Annual Report of the Secretary of the Navy for 1881, 27-81. See also Cooling, Gray Steel and Blue Water Navy, op. cit., 28, and Allard, "The Influence of the United States Navy," op. cit., 16.
56. Cooling, Gray Steel and Blue Water Navy, op. cit., 33-35. See also Misa, "Science Technology and Industrial Structure," op. cit. 71.
57. Leonard Swann, John Roach Maritime Entrepreneur, Annapolis, Maryland: United States Naval Institute Press, 1965. See Also David B. Tyler, The American Clyde, Dover, Delaware: University of Delaware Press, 1958, 54-55.
58. John W. Oliver, History of American Technology, New York, N.Y.: The Ronald Press, 1956, 324-326. See Also Allard, "The Influence of the United States Navy," op. cit., 10.
59. Allan Nevins, Abram S. Hewitt, New York, New York: Harper Brothers, 1933, 216. See also McHugh, Alexander Holley, op. cit., 286-288.
60. Allard, "The Influence of the United States Navy," op. cit., 23.
61. The early history of Midvale Steel is related by many authors but this important concern has strangely not become the subject of a lengthy monograph. Pertinent information is contained in Richard T. Nalle, Midvale and Its Pioneers, Philadelphia, Pa.: American Newcomen Society, 1948, 10-15; The Seventy-Fifth Anniversary of the Midvale Company, Philadelphia, Pa.: Midvale Steel Company, 1942, 12-15; and Philip Scranton and Walter Licht, Work Sights: Industrial Philadelphia 1890-1950, Philadelphia, Pa.: Temple University Press, 1986, 196-213.
62. Nalle, Midvale and Its Pioneers, op. cit., 14. See also Walther 1. Brandt, "Steel and the New Navy 1882-1895," (Unpublished M.A. Thesis, University of Wisconsin, 1920) 36.
63. Russell Wheeler Davenport (Memorial Volume), New York, New York: G.P. Putnam and Sons, 1905, 47-148. See also Brandt, "Steel and the New Navy," op. cit., 41.
64. Brandt, "Steel and the New Navy," op. cit., 39.

65. Ibid.
66. Ibid., 40.
67. Ibid.
68. A copy of this bill is contained in Vol. 22 of United States Statutes at Large, 288.
69. Brantd, "Steel and the New Navy," op. cit., 42.
70. Peck, Roundshot to Rockets, op. cit., 174. See also A History of Watervliet Arsenal: 1813 to Modernization 1982, Watervliet, N.Y.: United States Army-Watervliet Arsenal, 1983, 74-75.
71. Peck, Roundshot to Rockets, op. cit., 174-175.
72. William H. Jaques, "The Establishment of Steel Gun Factories in the United States," Proceedings of the United States Naval Institute, Vol. X, No. 4, 1884, 569.
73. "The Establishment of Steel Gun Factories in the United States" contains a complete description of the Board activities in Europe and a summary of its recommendations. See also Peck, Roundshot to Rockets, op. cit., 174-175.
74. Peck, Roundshot to Rockets, op. cit., 173-175. See also Watervliet Arsenal, op. cit., 74 and Brandt, "Steel and the New Navy," op. cit., 45.
75. Fritz, Autobiography, op. cit., 174-175.
76. John Ericsson's long and distinguished career is chronicled by William Conant Church, The Life of John Ericsson, Vols. I-II, New York, N.Y.: Charles Scribner's Sons, 1891.
77. H.F.J. Porter, "How Bethlehem Became Armament Maker: Reminiscences Covering the Introduction of Bessemer Steel, the Activities of Ericsson, Holley and Fritz and the Passing of the Builder of the Monitor," The Iron Age, Nov. 23, 1922, 1339-1341.
78. Misa, "Science Technology and Industrial Structure, op. cit., 78. See also Cooling, Gray Steel and Blue Water Navy," op. cit., 41-43 and "Captain William Henry Jaques," Transactions of the Society of Naval Architects and Marine Engineers, XXIX, 1916, 215.
79. Robert Sayre's daily diary entry for October 7, 1885, contained in the manuscript personal diaries of Robert H. Sayre in the collections of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
80. Minutes of the November 25, 1885, meeting of the board of directors of the Bethlehem Iron Company. See also Sayre Diary daily entry for November 25, 1885.
81. Minutes of the January 18, 1886, meeting of the board of directors of the Bethlehem Iron Company.
82. John Fritz, Autobiography of John Fritz, op. cit., 186.
83. Cooling, Gray Steel and Blue Water Navy, op. cit., 65.
84. Ibid., 67-74.
85. Minutes of the June 28, 1887 Meeting of the Board of Directors of the Bethlehem Iron Company. See also Annual Report of the Secretary of the Navy for 1887, 466-472.
86. Davenport Memorial Volume, op. cit., 57-60.
87. W.H. Jaques, "Description of the Works of the Bethlehem Iron Company," The Proceedings of the United States Naval Institute, Vol. XV, No. 4, 1889, 538-539.
88. Eugene G. Grace, "Manufacture of Ordnance at South Bethlehem," Yearbook of the American Iron and Steel Institute, 1912, 175-177.
89. Russell W. Davenport, "Production in the United States of Heavy Steel Engine Gun and Armor Plate Forgings," Transactions of the Society of Naval Architects and Marine Engineers, Vol. 1, 1893, 72-73.
90. S.G. W. Benjamin, "The Works of the Bethlehem Iron Company," Harper's Weekly, Vol. XXXV, No. 1886, 194-195. See also December 18, 1888, letter from J. M. Gledhill of Manchester, England, to John Fritz at South Bethlehem, Pa., contained in the Fritz Collection of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa. Gledhill was an official of Joseph Whitworth & Company; his letter contains detailed information on the equipment that is being shipped to Bethlehem.
91. April 8, 1890, letter of F.W. Barber at Le Creusot, France, to John Fritz of South Bethlehem contained in the Fritz Collection of the Hugh Moore Historical Park and Museums, Inc.
92. Misa, "Science Technology and Industrial Structure," op. cit., 88-89. See also History of the Manufacture of Armor Plate for the United States Navy: Philadelphia, Pa., American Iron and Steel Association, 1899, 1, and Cooling, Grey Steel Blue Water Navy, op. cit., 83-84.
93. Misa, "Science Technology and Industrial Structure," op. cit. 88.
94. "The Bethlehem Hammer," The Iron Age, July 13, 1893, 60-61.
95. Schroop, Historic Notes on Important Dates, op. cit. 1.
96. Grace, "Making Ordnance," op. cit., 176-177.

97. H. F. J. Porter, "The Radical Policy of Scrapping Costly Machinery," The Engineering Magazine, Vol. XX, No. 4, January 1901, 748; "The End of the Great Bethlehem Steam Hammer," Engineering News, April 10, 1902, 289. See also Coleman Sellers, "Hydraulic Forging Machines as compared with the Action of a Steam Hammer," Stevens Indicator, Vol. VI, No. 1, January 1889, 1-14, for an earlier examination of the superior qualities of hydraulic forging press.
98. "Making Heavy Steel Forgings: Notes upon the plant and product of the Bethlehem Steel Company," Machinery, Vol. VI, No. 2, October 1899, 36.
99. "The Bethlehem Hammer," op. cit., 62. See also "Making Heavy Steel Forgings," op. cit. 36, and "Manufacture of Guns and Armor at the Bethlehem Steel Works," Scientific American, Vol. LXXXII, No. 23, June 9, 1900, 359.
100. The description of the 14,000-ton-force press is derived from a number of sources including a measured drawing in the Bethlehem Steel Collection of the Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania. See also "The Bethlehem Hammer," op. cit., 62; "Making Heavy Forgings: Notes upon the plant and product of the Bethlehem Steel Company," Machinery, Vol. 6, No. 2, October 1899, 34-38; and "The Manufacture of Guns and Armor at the Bethlehem Steel Works, Part III," Scientific American, Vol. LXXXIII, No. 2, July 14, 1900, 24.
101. The description of the 15,000 horsepower engine is derived from the same sources as the description of the 14,000-ton-force forging press with the exception that no assembly drawings have yet been uncovered.
102. "The Manufacture of Guns and Armor at the Bethlehem Steel Works, Part II," Scientific American, Vol. LXXXIII, No. 23, June 9, 1900, 358-359.
103. History of the Manufacture of Armor Plate for the United States Navy, Philadelphia, Pa., American Iron and Steel Association, 1894, 3. See Also Joseph Frazier Wall, Andrew Carnegie, New York, N.Y., 1970, 646-690 and Cooling, Grey Steel, op. cit., 93-97.
104. Misa, "Science Technology and Industrial Structure," op. cit. 91, 93. See also Yates, Joseph Wharton, op. cit., 272-273.
105. New York Times of September 23, 1890. See also Misa, "Science Technology and Industrial Structure," op. cit., 95.
106. Misa, "Science Technology and Industrial Structure," op. cit., 97. See also Yates, Joseph Wharton, 314-316.
107. Yates, Joseph Wharton, op. cit., 278-280.
108. Memoir of Hayward Augustus Harvey, New York, N.Y. (privately printed memorial volume), 1900, 55-56.
109. Misa, "Science Technology and Industrial Structure," op. cit., 104-105.
110. Ibid. See also Hayward Augustus Harvey, op. cit., 57-58, 62-63.
111. Report of the Chief of the Bureau of Ordnance, Washington, D.C., Department of the Navy, 12. See also Hayward August Harvey, op. cit., 62-64.
112. Misa, "Science Technology and Industrial Structure," op. cit., 105.
113. Hayward Augustus Harvey, op. cit., 81.
114. Minutes of the board of directors meetings of the "Bethlehem Iron Company for June 26, 1892 and April 26, 1893 (Xerox copies at Hugh Moore Historical Park and Museums, Easton, Pennsylvania and Hagley Museum and Archives, Wilmington, Delaware). See also Yates, Joseph Wharton, op. cit., 284.
115. The board of directors minutes for 1894 contain additional details on the entry of the Bethlehem Iron Company into the international ordnance and armor market. At its November 8 meeting the directors approved "The employment of Capt. E.L. Zalinski at $1,500 annual retainer payable quarterly, first payment September 1, 1894. He to receive his travelling and other expenses at $10.00 per day Sundays accepted, when absent from New York on work for this company and a commission of 1% on the value of all orders secured by him and accepted by us. Captain Zalinski started for England en route to Brazil, China, Japan on the 31st of October . . . . That we had secured the good will and influence of Florit and Co. of New York to aid us in securing orders from Brazil for a commission of 5% on all sums paid to us by the Brazilian Government . . . . The appointment on August 17, 1894 of J. F. Meigs as Engineer of Ordnance at a salary of $5,000 per annum. J. F. Meigs sailed for Russia the latter part of October to hand in our bid for armor." The successful conclusion of J. F. Meigs' negotiations on behalf of the Bethlehem Iron Company was recorded in the following passage from the directors' meeting of December 26, 1894. "The President laid before the Board copies of cables sent to and received from Mr. Meigs in relation to the Russian armor plate contract dated December 20, 23, and 25 and called special attention to one received from Mr. Meigs under date of the 25th reading as follows

> We have done all possible to have contract signed at home. They demand it be signed here, delay fatal ships ready for armor. You have drawings sufficient for forgings for the first ship, other drawings and specifications will be sent with Inspectors who have their orders to leave payments to eighty percent in advance of delivery, conditions of contract very favorable, must sign it tomorrow or Freds (Krupp) may get it yet. We nearly lost it Saturday.

The board authorized Meigs to sign the contract and Bethlehem successfully completed the contract. See also Yates, Joseph Wharton, op. cit., 284.

116. Russell Wheeler Davenport, op. cit., 63.

117. "Manufacture of Armor Plate," unsigned manuscript dated January 29, 1895 in the Bethlehem Steel Corporation Historical Collection at the Hugh Moore Historical Park and Museums, Inc. Easton, Pennsylvania.

118. Captioned photograph of field ring for Niagara Falls hydroelectric plant being forged on the 14,000-ton-force hydraulic press at the Bethlehem plant contained in the Bethlehem Steel Corporation Historical Collection at the Hugh Moore Historical Park and Museums, Inc., Easton, Pa. See also Mark Fran, Niagara: A Selective Guide to Industrial Archaeology in the Niagara Peninsula, Toronto, Ontario: Ontario Society for Industrial Archaeology, 1982, 64-70.

119. Album of the World's Columbian Exposition, New York, N.Y.: Rand McNally, 1893, 48. This great axle was 45 feet in length, 33 inches in diameter and weighed over 56 tons.

120. Unpublished transcript of January, 1904, testimony by Captain Pendleton, superintendent of the Washington Naval Gun Factory, before the House Appropriations Committee, copies in the Bethlehem Steel Corporation Historical Collection, Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania and at the Hagley Museum and Archives, Wilmington, Delaware. It should also be noted that on January 14, 1904, Archibald Johnston, who was serving as the superintendent of Bethlehem's forging operations, sent a lengthy commentary on Captain Pendleton's testimony to E.M. McIvain, the president of the Bethlehem Steel Company. The following excerpts from this commentary impart additional information about the scope of Bethlehem's military contracts:

> Our gun forging output at the Forge for the last two years was less than 17% of our total forging product. We are able to increase it and willing that it should be increased to 75% of our yearly product.
>
> Total Government Work in Percent of New Contracts Taken

Year Ending	Value
1900	17.1%
1901	68.6% (This includes armor plate contract of Feb. 28, 1903)
1902	5.5%
1903	44.9% (This includes all government work, armor gun mounts etc. for both Army and Navy.)

> In the neighborhood of two years is consumed in the manufacture and completion of a 7 inch gun, we would point out that it is quite possible at all times to approximately foresee the date when guns will be needed and that this condition exists today as much as ever, i.e. the withholding of gun orders. This caused by the Navy Department putting too much dependence on the output of the Washington Gun Factory, and as before stated -- when it is found that the Government Factory cannot complete contracts on time they are sublet to outside contractors . . . . Captain Pendleton's statement here implies that they have given the Bethlehem Plant all the work they could do. As pointed out in my earlier remarks, that is not true, as the appended statement will show. The finished gun output for the past three (3) years is Machine Shop No. 2 follows:

Fiscal Year	Finished Guns lba.	Finished Guns Carriages-lbs.	Total Guns & Carriages-lbs.	Percentage of Total Shop Production
1901-02	863,397	28,288	891,685	3.1
1902-03	832,103	172,929	1,005,032	2.9
8 months 1903-04	475,625	211,630	686,555	2.7

Remarks: This is total gun work shipped from gun shop and includes both Navy and Army.

Copies of Johnston's commentary can be found in the Bethlehem Steel Corporation Historical Collection, Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania, and in the Archibald Johnston Collection at the Hagley Museum and Archives, Wilmington, Delaware.

121. Robert H. Sayre's diary entry for August 20, 1898, is as follows: "Left Bethlehem at 7:49 a.m. via CRR of N.J. for New York to see the parade of Sampson's fleet. Went direct to the office of the Bethlehem Iron Company where I met

Patty [his wife] and the boys who had come up from Atlantic Highlands. Had a fine view of the ships as they cam up the river, a grant sight to see the ships that had destroyed the Spanish Fleet on July 3rd." Sayre's diaries and his official invitation to the review are contained in the Robert H. Sayre Collection of the Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania.

122. Yates, Bethlehem of Pennsylvania, op. cit., 192. See also the Incorporation Papers of the Bethlehem Steel Company which is attached to the minutes of the Board of the Bethlehem Iron Company for May 19, 1899, copies at the Bethlehem Steel Corporation Historical Collection, Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania, and at the Hagley Museum, Wilmington, Delaware.
123. Yates, Joseph Wharton, op. cit., 301-303.
124. Diary Robert Sayre entry for May 28, 1901, contained in Robert H. Sayre Collection at the Hugh Moore Historical Park and Museums, Inc., Easton, Pennsylvania.
125. Yates, Joseph Wharton, op. cit, 302.
126. Ibid.
127. Robert Hessen, Steel Titan: The Life of Charles M. Schwab, New York, N.Y.: Oxford University Press, 1975. See also Wall, Andrew Carnegie, op. cit, 530-534, 787-789, 791.
128. Hessen, Steel Titan, op. cit., 149. See also Arundel Cotter, The Story of Bethlehem Steel, New York, N.Y., Moody Magazine and Book Company, 1916, 6-9.
129. Hessen, Steel Titan, op. cit., 146-147.
130. General Catalog of the Bethlehem Steel Company, Bethlehem, Pa., Bethlehem Steel Company, 1904, 74-75. See also Historic American Engineering Record Project of United States Steel's Homestead Plant (unpublished document, Washington, D.C. 1989).
131. Midvale 1867-1942, Philadelphia, Pa., The Midvale Steel Company, 1942, 19. See also Richard T. Nalle, "Midvale and its Pioneers," Address to the Newcomen Society of America, 1948, 19-20, and Cooling, Grey Steel Blue Water Navy, op. cit., 172.
132. Comparative Statement Ordnance and Armor Contracts awarded to United States steel companies, 1887-1904, copy in the Bethlehem Steel Corporation Historical Collection, Hugh Moore Historical Park and Museums, Inc. at Easton, Pennsylvania.
133. Hessen, Steel Titan, op. cit., 167-168.
134. Cotter, Story of Bethlehem Steel, op. cit., 10-12.
135. Ibid., 154.
136. Ibid., 169.
137. Ibid., 168-169.
138. Ibid., 168-169.
139. Hessen, Steel Titan, op. cit.,
140. "History of the Drop Forge Operations at the Bethlehem Plant" (unpublished manuscript contained in the Drop Forge Recording Project file at the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.) Included in this file is a letter written to Bethlehem Steel by Charles Lindbergh, expressing his appreciation for the reliability of the cylinders that the drop forge produced for the J-5 Wright Whirlwind engine of the spirit of St. Louis. The drop forge operation was closed on Oct. 30, 1989.
141. The Pocket Companion Containing Useful Information Appertaining to the Use of Steel as Manufactured by the Carnegie Steel Company, Pittsburgh, Pa., 1893 illustrates the dominance of Carnegie in the structural steel market.
142. Hessen, Steel Titan, op. cit., 173. See also Misa, "Science Technology and Industrial Structure," op. cit., 247.
143. Henry Grey, "A New Form of Structural Steel," Iron Age, June 17, 1897, 14. See also Henry Grey, "A New Process of Rolling Structural Steel Shapes," Engineering News, Vol. XLVI, Nov. 21, 1901, 387.
144. Hessen, Steel Titan, op. cit., 173.
145. Ibid.
146. Ibid., 176. See also Grey Mill, Recording Project Historical File of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
147. William Manchester, The Arms of Krupp, Boston, Massachusetts: Little Brown, 1968, 221-224.
148. 1908 Summary of International Armor Sales contained in Archibald Johnston papers, copies at the Hugh Moore Historical Park and Museums, Inc. Easton, Pa. and Hagley Museum and Archives, Wilmington, Delaware. See also Hessen, Steel Titan, op. cit., 179.
149. Hessen, Steel Titan, op. cit., 184.
150. Charles P. Neil, Report on the Strike at the Bethlehem Steel Works, South Bethlehem, Pennsylvania, Senate Document

521, 61st Congress, 2nd Session, 1910 contains the most comprehensive account of this strike.

151. W. Bruce Drinkhouse, The Bethlehem Steel Corporation: A History from Origin to World War I, Easton, Pa.: Northampton County Historical and Genealogical Society, 1969, 14. See also Bethlehem Shipbuilding Corporation, Ltd., Bethlehem, Pa., Bethlehem Steel Corporation, 1921 41-57.
152. The best account of the war-related activities of the Bethlehem Steel Corporation is contained in John K. Mumford, "The Story of Bethlehem Steel, 1914-1918" (unpublished manuscript set in type by the Bethlehem Steel Company printery, Bethlehem, PA. on March 22, 1943. See also Drinkhouse, Bethlehem Steel Corporation, op. cit., 14, and Hessen, Steel Titan, op. cit., 211.
153. Drinkhouse, The Bethlehem Steel Corporation, op. cit., 15.
154. Mumford, "The Story of Bethlehem Steel," op. cit., 14, 25.
155. Ibid.
156. The best history of the Redington site and its role in Bethlehem Steel's history is found in Ned D. Heindel, Iron Armor and Adolescents: The History of Redington, Easton, Pa.: Northampton County Historical and Genealogical Society.
157. Mumford, "The Story of Bethlehem Steel," op. cit., 50.
158. William Bradford Williams, Munitions Manufacture in the Philadelphia Ordnance District, Philadelphia, Pa.: A. Pomerantz Co., 1921, 314.
159. Ibid., 312.
160. Ibid.
161. Chapters 7 and 8 of Norman Friedman, United States Battleships: An Illustrated Design History, Annapolis, Maryland, United States Naval Institute Press, 1985, is a good summary of the U.S. Navy expansion planning and its effect on capital ship design.
162. The Bethlehem Booster, Vol. I, No. 14, November 15, 1918, 3.
163. The Properties and Plants of the Bethlehem Steel Corporation, Bethlehem, Pa.; The Bethlehem Steel Corporation, 1925, 7, 33-49. See also Mark Reutter, Sparrows Point: Making Steel - The Rise and Ruin of America's Industrial Might, New York, N.Y.: Summit Books, 1988, 107.
164. Hessen, Steel Titan, op. cit., 230.
165. The Properties and Plants of the Bethlehem Steel Corporation, op. cit., 7, 18127. See also Hessen, Steel Titan, op.cit., 231.
166. Thomas E. Leary, Elizabeth C. Sholes, From Fire to Rust, Business Technology and Work at the Lackawanna Steel Plant, 1894-1983, Buffalo, New York: Buffalo and Erie County Historical Society, 1987, 15.
167. The Properties and Plants of the Bethlehem Steel Corporation, op cit., 6-7.
168. Ibid.
169. January 8, 1923, memorandum of Archbald Johnston to Eugene Grace, copies in the Bethlehem Steel Historical Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pennsylvania and Hagley Museum, Wilmington, Delaware.
170. For an examination of the effects of the Washington Naval Disarmament on American warship development, see Norman Friedman, U.S. Battleships: An Illustrated Design History, op.cit., 181-209.
171. Record of Armor Facilities Production and Development - 1931-1942 Inclusive, unpublished report dated January 27, 1943, in the Bethlehem Steel Corporation Historical Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pennsylvania, 1.
172. Ibid.
173. Ibid.
174. Ibid.
175. Ibid.
176. Ibid.
177. Anthony Preston, The Complete Encyclopedia of Battleships, op. cit., 239-241. See also Norman Friedman, U.S. Battleships: An Illustrated Design History, op. cit., 243.
178. Ibid.
179. Ibid.
180. Photo album and clippings file of May 12, 1942, flood, Bethlehem Steel Historical Collection, Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
181. "Scrap Iron: It Becomes Precious Metal in U.S. Shortage of Steel," Life, Volume II, No. 1, August 25, 1941, 19-24.
182. "Chamber Told 33,000 Employed at Plant," Bethlehem Globe Times of August 3, 1944.
183. "Ordnance Chief Praises 5-Inch Guns Made Here," Bethlehem Globe Times, April 27, 1944.

184. "Construction of 16-Inch 50-Calibre Naval Ordnance," undated production history in the Bethlehem Steel Historical Collection of the Hugh Moore Historical Park and Museums, Inc., Easton, PA.
185. "Bethlehem Steel Company's Production of Shells, Armor, and Gun Forgings Up 27.5 Percent During Past Year," The Morning Call, Allentown, Pa., November 22, 1944.
186. Recollections. Bethlehem, Pa.: Public Affairs Department, Bethlehem Steel Corporation, 1980, 20.
187. Data on the end of armor plate production was provided to the author during April of 1990 by Mr. James S. Cox of Bethlehem. Mr. Cox is the retired superintendent of the BethForge Division of the Bethlehem Steel Corporation and it was under his direction that the last armor plate production took place.
188. The scrapping of the great 14,000-ton-force hydraulic forging press with its steam pumping engine are photographically documented in a special file located in the No. 1 Forge Shop maintenance records of the Bethlehem Steel Corporation Collections of the Hugh Moore Historical Park and Museums, Inc., Easton, Pa.
189. Data on the history of the current 12,000-ton-force hydraulic forging press was provided to the author during 1990 by Mr. James S. Cox of Bethlehem. Mr. Cox's last service as superintendent of BethForge was to engineer this upgrading of this press.
190. According to information supplied by Donald S. Young, an engineer at BethForge, production of 120mm forgings ceased during the autumn of 1984.
191. The Bethlehem Plant of the Bethlehem Steel Corporation. Bethlehem, Pa.: Bethlehem Steel Corporation, 1906, 13.
192. Scranton and Licht, Work Sights,. op. cit., 213.
193. Information on the closure of Homestead's forge shop was supplied to Mr. Mark Brown, historian for the HAER Monongahela Valley Project, by a former Homestead official, Mr. Justin Modic. Mr. Brown has kindly shared his research on this subject with the author.
194. October 27, 1989, memorandum of agreement between Chavanne-Ketin and the Bethlehem Steel Corporation creating a joint venture company to be known as Centex.

Appendix A
Summary of Description of the Historical Process for the Production of Armor Plate at the Bethlehem Plant

Production of armor plate at the Bethlehem Plant began with a steel ingot produced in an Open Hearth furnace, a type of steelmaking furnace placed into operation in the mid-1880s. Bethlehem used an alloy steel containing 3.25% nickel, which was added to impart both strength and toughness (resistance to fracture), for the production of armor plate. The molten steel was poured into an ingot mold to form a large cast ingot. After solidification had occurred, the ingot was removed from its mold and transported by railroad car from the open-earth area to the No. 1 Forge Shop.

At the Forge shop, the ingot was heated to a temperature in the range of 1800 to 2000 F and forged on a large hydraulic forging press. In order to maintain the ingot's malleability while it was elongated and reduced in thickness, it was removed from the press and reheated in adjacent furnaces at regular intervals during the forging process. During forging the ingot assumed the general rectangular shape of an armor plate.

The forged plate was then transferred by means of a railroad car to the No. 2 Treatment Shop where it was annealed to remove any internal strains that resulted from the forging process. The annealing process involved heating the plate in a car-bottom furnace to a temperature of 1250 to 1300 F, then cooling it slowly. Following cleaning and descaling the forged plate was ready for carburization, the first step in face hardening.

Face hardening is a process which combines raising the carbon level of what would be the outer surface of the armor plate with subsequent heat treatments (water quenching and tempering) to yield a plate with high hardness on the outer surface. This would allow the armor plate in service to shatter the impacting projectile while the remaining thickness of the armor plate would have sufficient strength and toughness to absorb the energy of the impact without catastrophic cracking. The use of face hardening of the Nickel alloy steel was known as the Harvey process.

For carburization (also known as carbonization), the surface of armor plate to be treated was covered with a layer of carbonaceous material, usually crushed charcoal or anthracite coal. The plate was then sealed in a furnace for heating to the treatment temperature which was generally 1890 to 1900 F. It was held at that temperature for 3 to 4 weeks to produce a carbon penetration of about 1 to 1½ inches. Following slow cooling and testing for the depth of carbon penetration, the plate was transferred back to the Forge Shop for reforging.

After reheating, the armor plate was reforged to reduce the thickness to that ordered and refine the internal grain structure. Subsequently the plate was transported back to the No. 2 Treatment Shop where it was again annealed. From there it was moved to a Machine Shop where some machining of the plate edges was done. This was followed by a bending operation which would shape the plate to the desired contour for the intended service.

The next operation, back in the No. 2 Treatment Shop, involved a carefully controlled heat treatment of the plate to produce the desired combination of high surface hardness and enhanced internal strength and toughness necessary for successful service as armor plate. This heat treating operation including at least one series of heating to temperatures of 1550 to 1660 F, water quenching, and tempering in the range of 1150 to 1200 F.

Final testing for properties and final machining of details completed processing of the individual armor plate pieces. Often however, trial assemblies of all the plates for certain components were made by the manufacturer. For example, all the plates for a battleship turret were assembled to check for proper dimensions and fit.

Appendix B
Construction of Additional Facilities, 1931 to 1942 Inclusive
compiled from company documents

1.	Press Forge		
	Date Completed	Item	Cost
	January 1934	#5 Forging Furnaces	$70,000
	January 1934	#2 Forging Furnace	39,218
	October 1935	Bending Press & 2 Furnaces	150,000
	May 1938	Broad Gauge Engine #110	7,500
	December 1938	New Trolley, Bend Press Crane	25,000
	March 1939	#6 Forging Furnace	130,000
	June 1940	New Transfer Buggy	9,000
	May 1941	#4 Press--New Press Cranes & Runs	182,484
	July/Sept. 1941	24-50 Ton RR Cars & 3 Heavy Duty Ingot Cars	198,000
	February 1942	New Transfer Buggy	5,834
	Total		$815,836
2.	Treatment		
	December 1938	75 Ton Crane	$ 60,000
	December 1938	Lengthen Armor Spray	11,500
	April 1939	#2 Hardening Furnace	57,000
	September 1940	Rotary Quench Tank	26,100
3.	Machine Shop #2, #3, #8		
	July 1934	1 Armor Saw Modernized	$ 9,000
	August 1935	1 14' Pit Planer #2 Shop	17,636
	March 1939	1 20' Pit Planer #2 Shop	45,000
	September 1940	2 12 table planer (New #8 Shop)	222,627
		Total	$294,263

The above facilities were provided at the various intervals noted to maintain the 560 N.T. capacity. Total expenditures for the period were $1,264,699.

Program Completed Sept. 1940 to Increase Capacity to 1344 N.T.

1.	Press Forge		
	Date Completed	Item	Cost
	April 1940	#25 & 26 Furnaces Complete With Changes to Bldg. etc.	$226,356
	2.	Treatment	
	April 1940	Bldg. Extensions to House 3 Addtl. Furnaces, also Chges. to Press Forge Pump House	170,210
	April 1940	3 Carbottom Furnaces #17-19	186,862
		Total	$357,072
3.	Machine Shop		
	May 1940	1 - 100-Ton Crane	$ 55,728
	June 1940	5 Bay Extension #3 Shop	94,961
	July 1940	2 Pit Planer Foundations	

	& L.O. Table	33,932
July 1940	2 Mesta Pit Planers	223,969
July 1940	1 Mesta Post Planer #8 Shop	74,070
July 1940	4 Carlton Radial Drills #2 Shop	43,632
	Total	$526,282

The above program totalling $1,109,710 again balanced out the various departmental facilities and provided a rated capacity increase of 224 N.T. of BB armor. A heavy BB program then underway required more finishing equipment due to increased degree of finish on this type of armor.

Programs Completing July 1941 and February 1942 to Increase Capacity to 1568 N.T. and 2040 N.T. Respectively. (National Defense Program Project #1).

1. Press Forge

Date Completed	Item	Cost
May 1941	Fireless Locomotive	$ 11,523
August 1941	1 100-ton Crane for 9 Bay Extension	64,762
August 1941	9 Bay Extension	106,500
November 1941	Stockyard Crane (Remod. from Bend Press	48,423
November 1941	2 Carbottom Preheat Furnaces (Yard)	66,524
November 1941	New Bend Press Crane 100-ton	65,847

2. Treatment
(Under Project #2--Blue Mountain Forge)

August 1941	3 Carbottom Carburizing Furnaces	$199,500
January 1942	#13A & #20 Carbottom Furnaces	127,055
	Total	$326,555

3. Machine Shop #3

July 1941	1 100-Ton Scale	$ 8,814
November 1941	1 Mesta Post Planer	101,697
February 1942	3 2-Spindle Ohio Mills #6 Shop	101,464
May 1942	1 100-Ton Crane	64,782
July 1942	2 Milling Machines Ingersoll, Morton	343,414
September 1942	4 Carlton Vert. Drills	48,634
December 1942	Car Haul	11,521
December 1942	3 G&L Horiz. Boring Mills (1 Received)	26,958
	Total	$707,284

Total Expenditure for this period $1,574,912.

Program Completed October 1942 to Increase Capacity to 3166 N.T. (National Defense Program, Project #13)

Project #13 covered the building and equipping of Armor Treatment Plant #9 located in the East Lehigh development. The completed cost of the project is estimated at $5,946,988 of which $4,822,092 has been expended as of December 31, 1942.

The principal facilities included under this project are as follows:

Buildings - 1 bay 80' x 1180' and 1 bay 80' x 620' plus auxiliary furnace leantos, etc. (See Photostat "D").
3 Motor Generators and Transformers
River Water System

12 Heavy Duty RR Flat Care
3 - 150-Ton Motorized Transfer Cars
2 - 75-Ton Turning Rigs
7 - 100 - 20-Ton Cranes, 75' Span
*1 - 100/20-Ton Crane 59" - 2½" Span
15 - 14' x 50' Carbottom Furnaces
2 - 16' x 50' Carbottom Furnaces
2 - 14' x 50' Carbottom Recirculating Furnaces
1 - 14' x 50' Carbottom Furnace (Hardening)
1 - 6500-Ton Bending Press
Armor Plate Spray Quench
1- Laydown Pad 2 Layout Plates
3 - "Molino" Drills (for tests)
1 - Sandblasting Machine
Scarfing, Scaling and Grinding Equipment
*Located in No. 3 Shop - South Aisle.

The above plant was designed to produce an increase in capacity of 1120 N.T. per month effective October 1942. Allocations conferences with the Bureau of Ordnance in April 1942 resulted in an arbitrary increase in estimated total plant capacity to 3920 N.T. per month instead of the planned Operating Department figure of 3166 N.T. noted above.

Summary of Expenditures for New Facilities

Program	Amount	Capacity	Increase
1931 to 1942 (No Specific Program)	$1,264,999	560 N.T.	None
December 1939 (M.O. 1136)	929,518	1120 N.T.	560 N.T.
September 1940 (M.O. 1141)	1,109,710	1344 N.T.	224 N.T.
July 1941 and February 1942	1,574,912	2040 N.T.	696 N.T.
October 1942	5,946,988	3166 N.T.	1126 N.T.
Grand Total	$10,826.127		2609 N.T.

Appendix C
Taken from pages 4-6 of Historical Sketch of the Bethlehem Steel Company and Bethlehem Steel Corporation, 1912

In its ordnance work the Bethlehem Company has not only produced material of the highest quality, but has always been a leader in the design and development of devices now in use not only by the United States but also by the great countries of Europe.

Some indication of the magnitude of the business of this Company in munitions of war may be had from the partial list of such material which it has manufactured:

ARMOR PLATE.

FOR THE UNITED STATES GOVERNMENT, about 80,020 tons for U.S.S. Puritan, Amphitrite, Monadnock, Terror, Monterey, Maine (1st), Texas, Indiana, Massachusetts, Oregon, Iowa, Brooklyn, Kearsage, Kentucky, Illinois, Alabama, Florida, Wyoming, Maine (2nd), Missouri, Ohio, Pennsylvania, Colorado, Maryland, West Virginia, Nebraska, Georgia, Milwaukee, St. Louis, Louisiana, Washington, Vermont, Minnesota, Kansas, Idaho, Mississippi, North Carolina, New Hampshire, Michigan, South Carolina, Delaware, North Dakota, Utah, Arkansas, Wyoming, New York, Oklahoma, Nevada and for the land turrets in the Philippines.

FOR THE IMPERIAL GOVERNMENT OF RUSSIA, about 4,575 tons for the I. R. S. Petropavlovsk, Sevastapol, Admiral Seniavin, Admiral Oushakoff, Rostislav, Retvizan, Variag and Alexander III.

FOR THE HIGH GOVERNMENT OF ARGENTINA, (contract now under execution,) about 8,870 tons for the Moreno and Rivadavia.

FOR THE ROYAL GOVERNMENT OF ITALY, (contract now under execution,) about 2,050 tons for the R. H. S. Giulio Cesare and 1,457 tons for the R. H. S. Andrea Dorea.

GUNS AND MOUNTS.

FOR THE UNITED STATES GOVERNMENT.

1	18"	Breech Loading Rifle.
5	14"	Breech Loading Rifles.
49	12"	Breech Loading Rifles.
55	12"	Breech Loading Mortars.
58	10"	Breech Loading Rifles.
25	8"	Breech Loading Rifles.
44	7"	Breech Loading Rifles.
42	6"	Rapid Fire Guns.
104	5"	Rapid Fire Guns.
74	4"	Rapid Fire Guns.
60	3"	Rapid Fire Guns.
65	3"	Field Guns.
2	3"	Field Batteries.
19	12"	Disappearing Gun Carriages.
41	10"	Disappearing Gun Carriages.
20	6"	Disappearing Gun Carriages.
320	3"	Gun Caissons.
192	3"	Gun Limbers.
126	4.72" and 6"	Siege Limbers and Caissons.
2	14"	Turret Mounts.
10	12"	Turret Mounts
8	8"	Turret Mounts.
37	7"	Pedestal Mounts.
25	6"	Pedestal Mounts.
79	5"	Pedestal Mounts.
24	4"	Pedestal Mounts.
10	Sets	Flame Proof Hoists for 12" Turrets.
5	Sets	Turning Gear for 12" Turrets.

FOR THE IMPERIAL OTTOMAN EMPIRE.

2	6"	Guns and Mounts.
8	4.72"	Guns and Mounts.
16	Minor Calibre Guns	

FOR THE REPUBLIC OF MEXICO

8	4"	Guns and Mounts.
12	Minor Calibre Guns and Mounts.	

FOR THE HIGH GOVERNMENT OF ARGENTINA. (Contract now under execution.)

24	12"	Guns and Turret Mounts.
24	6"	Guns and Mounts.
80	4"	Guns and Mounts.
16	Minor Calibre Guns and Mounts.	

GUN FORGINGS. (Furnished to be assembled at Government Arsenals.)

FOR THE UNITED STATES GOVERNMENT.

1 Set	16"	Breech Loading Rifles.
40 Sets	14"	Breech Loading Rifles.
24 Sets	13"	Breech Loading Rifles.
154 Sets	12"	Breech Loading Rifles.
119 Sets	12"	Breech Loading Rifles.
113 Sets	10"	Breech Loading Rifles.
105 Sets	8"	Breech Loading Rifles.
690 Sets	5" to 7"	Breech Loading Rifles.
699 Sets	Smaller Calibre.	

PROJECTILES.

FOR THE UNITED STATES GOVERNMENT.

10	18"	Projectiles.
6	16"	Projectiles.
850	14"	Projectiles.
400	13"	Projectiles.
10,200	12"	Projectiles.
2,200	10"	Projectiles.
20,200	8"	Projectiles.
6,600	7"	Projectiles.
8,200	6"	Projectiles.
18,700	5"	Projectiles.
2,600	4"	Projectiles.
245,400	3"	Projectiles.
144,000	Minor Calibre Projectiles.	

FOR THE IMPERIAL OTTOMAN EMPIRE.

1,000 Rounds 6" Ammunition

2,900 Rounds 4.72" Ammunition.

5,000 Rounds Minor Calibre Ammunition.

FOR THE REPUBLIC OF MEXICO.

1,160 Rounds 4" Ammunition.

4,400 Rounds Minor Calibre Ammunition.

FOR THE SMALLER AMERICAN REPUBLICS.

16,300 Rounds Minor Calibre Ammunition.

FOR THE HIGH GOVERNMENT OF ARGENTINA. (Contract now under execution.)

2,000 Rounds 12" Ammunition.

12,000 Rounds 6" Ammunition.

19,200 Rounds 4" Ammunition.